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Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

An Annotated Bibliography of Nondestructive Testing of Concrete: 1975-1984

by
N. G. Zoldners
and
J. A. Soles

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AN ANNOTATED BIBLIOGRAPHY ON NONDESTRUCTIVE TESTING OF CONCRETE: 1975-1984

N.G. Zoldners and J.A. Soles

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FOREWORD

Canada Centre for Mineral and Energy Technology (CANMET) has been in the forefront of non-destructive testing of metals for over 40 years. During the past 20 years these methods have also been applied to the testing of cementitious materials in general, and concrete in particular. As a result, considerable data and experience in the use of non-destructive techniques have accumulated. The information had been summarized in the Mines Branch (CANMET's former name).

Monograph 875, issued in 1968, and a 16-mm colour movie of 30 minutes' duration was produced in 1980. Monograph 875 became the basis of the American Concrete Institute publication "Testing Hardened Concrete: Nondestructive Methods", issued in 1977.

As part of technology transfer and information dissemination, CANMET in association with the American Concrete Institute, the National Bureau of Standards U.S.A. and the Canadian Society for Civil Engineering sponsored an international conference on In Situ, Non-destructive Testing of Concrete, which was held in Ottawa, Canada in 1984. The Proceedings of the conference are available from the American Concrete Institute as ACI-SP82. One of the papers included in the Proceedings was the CANMET-sponsored/Annotated Bibliography on Non-Destructive Testing of Concrete: 1975-1983, by N.G. Zoldners and J.A. Soles. That bibliography did not include papers presented at the 1984 conference. The current one is an update, which includes summaries of the papers published in ACI-SP82. It is hoped that this bibliography will be of use to practising engineers, technologists and graduate students engaged in testing of concrete and strength evaluation of concrete structures.

V.M. Malhotra
Head, Construction Materials
CANMET

July 28, 1985

PRÉFACE

Le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) est au premier rang des essais non destructifs des métaux depuis plus de quarante ans. Au cours des 20 dernières années, les méthodes d'essais non destructifs ont été appliquées aux essais de matières de cimentation en général et tout particulièrement aux essais du béton. En conséquence, une grande expérience et une quantité considérable de données ont été acquises sur les techniques non destructives. Ces renseignements ont été résumés par la Direction des Mines (ancien nom de CANMET).

La Monographie 875 a été publiée en 1968 et un film de 16 mm en couleur, d'une durée de 30 minutes, a été produit en 1980. La Monographie 875 a servi de base à une publication de l'American Concrete Institute "Testing Hardened Concrete: Nondestructive Methods" publiée en 1977.

Dans le cadre du transfert de la technologie et de la diffusion de l'information, CANMET associé à l'American Concrete Institute, au National Bureau of Standards (É.-U.) et à la Société canadienne de génie civil a parrainé la conférence internationale sur les Essais non destructifs in situ du béton, tenue à Ottawa, Canada en 1984. Le Compte rendu de la conférence a été publié et on peut se le procurer de l'American Concrete Institute sous ACI-SP82. Une des communications présentées dans le compte rendu est la Bibliographie annotée sur les essais non destructifs du béton: 1975-1983 par N.G. Zoldners et J.A. Soles; ce document a été parrainé par CANMET. Cette bibliographie ne comprenait pas les communications présentées lors de la conférence de 1984, alors que la présente bibliographie est une mise à jour qui comprend les résumés des communications publiées dans le document ACI-SP82. Il est à souhaiter que cette dernière bibliographie sera utile aux ingénieurs, aux technologistes et aux étudiants diplômés dans le cadre de leurs travaux portant sur les essais du béton et l'évaluation des structures en béton.

V.M. Malhotra
Chef, Matériaux de construction
CANMET

le 28 juillet 1985

AN ANNOTATED BIBLIOGRAPHY ON NONDESTRUCTIVE TESTING OF CONCRETE: 1975-1984

N.G. Zoldners* and J.A. Soles**

Synopsis

Non-destructive concrete testing methods provide construction engineers and concrete technologists with useful tools for quality control of concrete and for evaluating the strength and durability of existing structures. This annotated bibliography, chronologically arranged, compiles literature published from 1975 to 1984 on innovations and modifications of non-destructive methods used for the testing of concrete. Attention was focused on the new methods used for monitoring concrete deterioration, crack development, and corrosion of reinforcement bars.
The journals, symposia, and books selected for review have international stature and contain state-of-art experimental works from diverse laboratories. Authors' abstracts, or their translations, are included when possible, to assist the concrete engineer in determining the applicability of a method to provide needed data.
This study was made possible with a Canadian Government contract awarded to the senior author. This is an updated edition of the work published in the American Concrete Institute special paper SP-82.

UNE BIBLIOGRAPHIE ANNOTÉE SUR LES ESSAIS NON DESTRUCTIFS DU BÉTON: 1975-1984

N.G. Zoldners et J.A. Soles

Résumé

Les méthodes d'essais non destructifs du béton fournissent aux ingénieurs de la construction et aux technologistes du béton des outils utiles pour contrôler la qualité du béton et pour évaluer la résistance et la durabilité des structures en béton actuelles. La présente bibliographie annotée est disposée en ordre chronologique et présente une compilation de la documentation allant de 1975 à 1984 sur les innovations et les modifications apportées aux méthodes non destructives utilisées dans le cadre des essais du béton. Les nouvelles méthodes utilisées pour surveiller la détérioration du béton, la fissuration et la corrosion de l'armature ont fait l'objet d'une attention particulière dans ce document.
Les revues, les symposiums et les livres choisis revêtent tous une importance à l'échelle internationale et présentent l'état actuel des travaux de recherches provenant de différents laboratoires. Dans le but d'aider l'ingénieur du béton à évaluer une méthode qui pourrait lui fournir des données utiles, on a inséré dans la bibliographie les résumés préparés par les auteurs, ou leur traduction dans la mesure du possible.

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N.G. Zoldners, P.Eng., is a consulting materials engineer specializing in concrete technology. He has carried out extensive research on the properties and testing of concrete, and has published many papers on this subject in the ASTM, ACI, and other professional journals.

J.A. Soles, Ph.D., P.Eng., is a mineralogical research scientist with the Canada Centre for Mineral and Energy Technology (CANMET, EMR). He is involved with the study of reactive phases in concrete systems.

Keywords

Acoustical methods (emission, shock); break-off method; chlorides in concrete; coating bond; combined NDT methods; concrete cracking; concrete strength (compressive, flexural, tensile); corrosion monitoring; damping properties; delamination detection; dielectric technique; durability measurement; electrical methods; electrical resistivity m.; electromagnetic method; gamma radiography; radiometry; half-cell potential m.; holographic technique; infrared thermography; in situ NDT methods; magnetic methods; maturity technique; mechanical sonic pulse method; microwave absorption; moisture content determination; neutron moisture gages; nuclear test methods; penetration resistance m.; permeability tests (air, chlorides, gas, water); petrography; photoelastic methods; polarization resistance technique; pull-off method; pulse echo technique; pulse velocity method; radar penetration technique; radioactive methods; radiation shielding tests; rebar concrete cover measurement; rebar corrosion monitoring technique; rebound hammer (Schmidt's); resonant frequency method; surface hardness methods; TV inspection method; thermoluminescence technique; ultrasonic pulse methods.

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1975

1. Amsler, D.E., and Chamberlin, W.P. "Depth of concrete cover over bridge deck reinforcement"; Transportation Research Record, Transportation Research Board; No. 535, 1975, pp. 73-82.

Fifty concrete bridge deck spans in New York state were surveyed with a pachometer for depth of clear concrete cover. Compliance with a design requirement for a minimum of 51 mm (2 in.) occurred at 77.3% of the locations measured. Spans having a high degree of compliance also tended to have relatively uniform cover depths. The distribution of cover depths on individual spans was generally not normal, and a construction tolerance of ±13 mm (±1/2 in.) was determined to be reasonable for the type of requirement under which the decks were built.

Keywords: *bridge decks; concrete durability; concrete pavements; cover; reinforcing steels.*

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2. Abramowicz, M., and Ciaś, A. "Petrographic and chemical tests on some reactor shield concretes" (in Polish); Archiwum Inzynierii Ladowej (Warsaw); Vol. 21, No. 3, 1975, pp. 537-544.

Petrography of concrete cuttings from a nuclear reactor was investigated microscopically. Contents of crystallographic water were measured at a temperature of 900°C by means of Penfield's method. The test results showed that petrographic methods are suitable for assessing the quality of concretes for nuclear reactor radiation shielding. As to the homogeneity of concretes, the worst results were obtained for barite concretes. Strength tests on those confirmed this conclusion.

Keywords: *barite; heavyweight concretes; microscopy; nuclear reactors; petrography; radiation shielding.*

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3. Aronsson, R., Fagerlund, G., and Larsson, B. "Impact strength of concrete in piles" (in Swedish); CBI Report No. 7541, Swedish Cement and Concrete Research Institute, Stockholm; 1975.

Specifications imposed on concrete for piles relate only to the compressive strength. It is suggested that some form of impact resistance or impact strength should instead be introduced as the criterion of quality. This report describes a test method which can assist in finding types of concrete suitable for use in driven piles.

Keywords: *concrete piles; foundations; impact strength; impact tests; pile-driving.*

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4. Bellander, U. "Tests on methods of observation for field investigation dealing with bond between double-T floor slabs and concrete topping" (in Swedish); CBI Research Report No. 4:75, Swedish Cement and Concrete Research Institute, Stockholm; 1975.

In calculating the load-carrying capacity of the precast concrete slab, it is assumed that the slab and the concrete topping act as a structural unit. To find out to what extent the topping and the slab act together, nondestructive test methods (impact hammer, rebound hammer, ultrasonic and vibration tests) were studied under laboratory conditions. Two states were investigated: the existing bond and the disrupted bond between the slab and the topping at the point of contact. No test method gave a reliable indication of the state of disrupted bond; however, contact between the layers was shown.

Keywords: *bond (concrete to concrete); concrete slabs; construction joints; impact hammer tests; impact tests; non-destructive tests; sonic tests; ultrasonic tests; vibration.*

5. Baker, P.J. "Air testing of concrete pipelines", Proceedings, 8th International Congress of the Precast Concrete Industry, BIBM, (Stresa, May 12-19, 1975), Cement and Concrete Association, London, England; 1975, 30 pp.

Concrete pipelines laid for transporting sewage and other liquids are required to undergo leakage tests prior to acceptance by the user. A well-established and accepted method of checking for leaks is to undertake a water test. An alternative is to introduce air at low pressure into the pipeline and to measure the subsequent fall in pressure.

Keywords: *air; permeability; pipe joints; pipes (tubes); seepage; sewer pipes; tests; water pipes; waterproofing.*

6. Bickley, J.A. "Practical application of the maturity concept to determine in-situ strength of concrete", Transportation Research Record, Transportation Research Board; No. 558, 1975, p. 45.

The CN Tower is the highest free-standing concrete structure in the world. The slipformed concrete superstructure is 450 m high. It contains 30 580 m^3 of concrete. The accelerated test used during slipforming was the 48-h autogenous test devised by Smith and Tiede. The last three months of slipforming were carried out from Dec. 1973 to Feb. 1974, the coldest period of the Canadian winter. Maturity testing was done to check that as the slipform rose, the concrete exposed to winter conditions achieved adequate strength. Thermocouples inserted during every shift were monitored and in-place strength calculated.

Keywords: *accelerated concrete tests; cold-weather construction; compressive strength of concrete; low temperature; maturity concept; slipform construction; towers.*

7. Brunarski, L., and Runkievicz, L. "Principles and application examples of nondestructive methods in testing of concrete structures" (in Polish); Instytut Techniki Budowlanej, Warsaw, Poland; 1975, 240 pp.

This report contains theoretical principles of nondestructive testing of concrete by surface hardness, ultrasonic methods, radiological methods, and electromagnetic methods, as well as a statistical analysis of test results. Many examples of applications of nondestructive methods for testing concrete, reinforced concrete, and prestressed structures are given.

Keywords: *nondestructive tests; prestressed concrete; radiography; statistical analysis, ultrasonic tests.*

8. Gast, R. "Determination of the composition of hardened concrete by means of a stereological method" (in German); Beton Herstellung und Verwendung, (Dusseldorf, FRG); Vol. 25, No. 10, Oct. 1975, pp. 347-350.

This report describes the stereological method regarding its theoretical principles and bases, its practical realization, as well as some results obtained on test concretes.
The composition of concrete may be determined by chemical processes. Evaluation of the results is difficult where the aggregate contains soluble ingredients. The proposed stereological method is independent of the content of soluble ingredients in concrete, and calculates, among other values, the cement content and the water-cement ratio after determining the volumes and densities of the concrete constituents.

Keywords: *cement content; hardened concretes; mechanical tests; water-cement ratio.*

9. Ghosh, R.K., and Vijayaraghavan, S.R. "Estimation of the cement content of hardened concrete by a nuclear method", Indian Concrete Journal; Vol. 49, No. 4, Apr. 1975, pp. 102-110.

The paper suggests a nuclear technique for estimating the cement content of hardened concrete on the basis of the number of hydrogen nuclei present in it. The general principles basic to the method are briefly discussed, and then the suggested technique is described. The inaccuracies associated with this estimating technique and the correction necessary to improve the degree of accuracy are analyzed in detail. Laboratory tests indicate that the technique yields results with a good degree of accuracy.

Keywords: *cement content; concrete testing; fast neutrons; hardened concrete; hydration of cement; hydrogen nuclei; non-fixed water; nondestructive testing; nuclear instrumentation.*

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10. Iddings, F.A., Arman, A., Pepper, C.E., Aubert, W.E., and Landry, J.R. "Determination of cement in concrete by activation analysis with Californium-252", Transportation Research Record, Transportation Research Board; No. 539, 1975, pp. 20-26.

Results from neutron activation analysis of in-place and plastic concrete samples are presented. Data were obtained by equipment suitable for and operated under field conditions. The system described for determination of cement content of in-place concrete includes a 35-μg Cf-252 source, portable activation/shield assembly with remote operating cable, commercially available detector, and electronics. An analysis of in-place concrete takes 22 min. Neutron activation analysis offers a rapid, simple, field-operational procedure for measurement of cement content. Besides these advantages, activation analysis allows the use of large, representative samples and offers considerable freedom from interferences.

Keywords: *cement content; chemical analysis; field tests; fresh concretes; neutron activation analysis.*

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11. Knudsen, T., and Thaulow, N. "Quantitative microanalyses of alkali-silica gel in concrete", Cement and Concrete Research; Vol. 5, No. 5, Sept. 1975, pp. 443-454.

By the combination of scanning electron microscope, energy dispersive X-ray spectrometer, and computer, quantitative analyses of microvolumes of alkali-silica gel from cracks in concrete were carried out at the reaction site. The composition of the gels analyzed in this investigation compares favourably with gels synthesized by Kalousek in 1944.

Keywords: *alkali-aggregate reactions; alkali content; concretes; electron microscopes; silica gel; X-ray spectroscopy.*

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12. Malhotra, V.M. "Evaluation of the pullout test to determine strength of in-situ concrete", RILEM (Réunion Internationale des Laboratoires d'Essais et de Recherches sur les Matériaux et les Construction) Bulletin, Materials and Structures, Paris, France; No. 8:43, 1975, pp. 19-31.

A degree of correlation exists between standard 15- by 30-cm concrete test cylinders and the pullout strength of concrete under field-cured conditions. The ratio of pullout strength vs compressive strength at three days varies from 18% for 32 MN/m concrete to 46% for 8 MN/m. At 28 and 91 days, the ratio varies from 20 to 29% and 19 to 29%, respectively. The pullout test is superior to the rebound hammer and the Windsor probe tests because a greater depth of concrete is tested. However, the pullout test has to be planned in advance, and pullout assemblies have to be set in to the form work before concrete is placed.

Keywords: *concrete strength; hydraulic pump; pressure gauge; pullout assembly; tension ram; nondestructive testing.*

13. Malhotra, V.M., and Carette, G. "Comparison of pull-out strength of concrete with compressive strength of cylinders and cores, pulse velocity and rebound hammer number", CANMET Report 76-8, Mineral Sciences Laboratories, Dept. of Energy, Mines and Resources, Ottawa; 1975, 42 pp.

This paper presents comparisons of pull-out strength of concrete with compressive strength of cylinders and cores, pulse velocity and rebound number. Briefly, a pull-out test (a relatively new technique), measures with a special tension ram the force required to pull out a specially shaped steel rod, whose enlarged end has been cast into the concrete. In this study, pullout tests were performed on 61 by 61 by 30 cm (2 by 2 by 1 ft) concrete blocks. Compressive strengths were obtained on 10 by 20 cm (4 by 8 in.) and 15 by 30 cm (6 by 12 in.) cylinders; also 10 by 20 cm (4 by 8 in.) cores were drilled from the blocks. In addition, pulse velocity measurements and Schmidt rebound hammer readings were taken for these blocks.

Keywords: *compressive strength; cores; curing; cylinders; impact hammer tests; pull-out tests; ultrasonic tests.*

14. Manns, W. "Water content of concrete at high temperatures" (in German), Betontechnische Berichte Beton-Verlag, Dusseldorf, FGR; 1975, pp. 17-31.

In some applications, concrete is continuously subjected to temperatures exceeding 100°C. Knowledge of the water content is essential when for instance, the shielding effect of concrete against neutron beams at high temperatures has to be evaluated. The content of combined water in dry concrete is the initial value for the water content at higher temperatures. It is made up of the water contained in the hardened cement paste and in the aggregate. After 28-day storage the dry-hardened cement paste contains 14 to 19% combined water; at later ages, 20 to 22% can be expected. Combined-water content of ordinary aggregate is low: 0.5 to 2.0%. For aggregates containing water of crystallization, the combined water content is higher: 10 to 13% by weight of concrete.

Keywords: *cement pastes; drying; high temperature; hydration; moisture content; water; water-cement ratio.*

15. Mukherjee, P.K. "Practical application of maturity concept to determine in-situ strength of concrete", Transportation Research Record, Transportation Research Board, No. 558, 1975, pp. 87-92.

Strength of field-cured concrete has been estimated by correlating the maturity to strength, the maturity being a function of age and curing temperature. Additional standard cylinders are cast, and the maturity of in-place concrete is determined from thermocouples cast into the concrete or maturity meters installed during placing of the concrete. Standard cylinder strength and field maturity are then correlated. The in-place strength is determined by using constants for the concrete used.

Keywords: *age-strength relation; compressive strength; concretes; curing; field tests; laboratory tests.*

16. "Non-destructive testing of concrete (Part IV)" (in Dutch); Netherlands Committee for Concrete Research (Zoetermeer); Rapport 69, 1975, 87 pp.

Until recently, methods commonly employed for determining the compressive strength of concrete by nondestructive testing have consisted of either measuring the velocity of propagation of ultrasonic pulses or determining the rebound number with a Schmidt rebound hammer.
A much more accurate result for compressive strength can be derived from the combination of the pulse velocity and the damping constant of the concrete.

Keywords: *compressive strength; concretes; damping; field tests; impact hammer tests; nondestructive tests; ultrasonic tests.*

17. Nwokoye, D.M. "Influence of binary aggregate proportions upon some concrete properties", Magazine of Concrete Research, London, England; Vol. 27, No. 93, Dec. 1975, pp. 229-238.

Ultrasonic pulse velocity tests were used to examine the internal structure of concrete and its influence upon certain physical and mechanical properties. It is found that binary aggregate proportions affect not only (a) the relationships between paste pulse velocity and cube strength, as well as (b) the dynamic elastic moduli of cement paste, mortar, quasi-mortar (cement paste plus coarse aggregate), and concrete phases, but also have some influence on the workability of concrete.

Keywords: *cement content; coarse aggregates; mix proportioning; concretes; modulus of elasticity; mortars (material); ultrasonic tests; workability.*

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18. Rajagopalan, P.R., and Prakash, J. "Non-destructive testing of pile foundations", Indian Concrete Journal (Bombay, India); Vol. 49, No. 12, Dec. 1975, pp. 363-365, 377.

Cast-in-place pile foundations present a unique problem in nondestructive testing, since only the top of the foundation is accessible, even though the entire depth of the foundation is required to be tested. Of the many methods available, the ultrasonic pulse method is one for checking the foundation at any desired depth nondestructively. In this work, pipes 2.5 cm in diameter were embedded along the depth of the foundation while it was being cast. The transmitting and receiving probes were introduced into the pipes, and fluid was used for acoustic coupling between the transducers and the pipes.
The method can be used for testing pile foundations up to 75 cm in diameter and 20 m in depth.

Keywords: *concrete piles; foundations; nondestructive tests; ultrasonic tests.*

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19. Rechenberger, W. "Young concrete in highly aggressive water" (in German); Betontechnishe Berichte, 1975, Beton-Verlag GmbH, Dusseldorf, West-Germany; pp. 57-65.

Tests have been carried out in which concrete specimen (10-cm cubes) 3 and 6 h old were stored for a prolonged time in highly aggressive sulphate- and carbonic acid-containing water. With an impact ball hammer test and a chemical and analytical determination of the entry depth of the sulphate, it has been found that for the chemical resistance of the concretes it does not matter whether they are subjected to highly aggressive liquids immediately after their production or after seven days of curing.

Keywords: *acids; chemical attack; chemical tests; immersion tests; impact tests; nondestructive tests; sulphate attack.*

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20. Stratfull, R.F., Jurkovich, W.J., and Spellman, D.L. "Corrosion testing of bridge decks", Transportation Research Record, Transportation Research Board; No. 539, 1975, pp. 50-59.

When the corrosive half-cell potentials on a bridge deck exceed about 10%, or when corrosion-caused delamination exceeds about 1% of the deck area, the chloride content is too great. For the average depth of reinforcing steel, the quantity of chloride apparently needed to cause corrosion was statistically related to the maximum amount at the 95% confidence limit of 0.6 kg/m^2. Although the half-cell potential of -0.35 V to the saturated copper/copper sulphate half-cell (CSE) is indicative of active corrosion, an equipotential contour map is the most reliable means for evaluating the corrosion activity of steel in concrete.

Keywords: *bridge decks; chlorides; corrosion; corrosion tests; reinforced concrete; reinforcing steels.*

21. Van Daveer, J.R., and Sheret, G.D. "Concrete cover story", Report No. FHWA-DP-15, Federal Highway Administration, Arlington, D.C.; 1975, 66 pp.

In 1972, a nation-wide study was undertaken by the FHWA to measure the clear cover over the top mat of bridge deck reinforcing steel. This report contains the study findings. Typically, of the bridges tested, the average concrete cover depth exceeded design requirements. However, because the cover depth distribution is near normal, a significant portion of the deck (~30%) has less than design cover. Those bridges that met design cover requirements by 100% have an average cover depth ~1.9 cm (~3/4 in.) greater than design.

Keywords: *bridge decks; concretes; corrosion; cover; durability; embedment; reinforcing steels; thickness.*

1976

22. Bažant, Z.P., and Klud-Um, W. "Quest for a quantitative model of corrosion processes and thermal cracking in ocean concrete structures", Proceedings, Conference on Behaviour of Offshore Structures (Trondheim, Norway, Aug. 1976), Norwegian Institute of Technology, Trondheim; Vol. I, pp. 593-604.

Durability of concrete structures in seawater depends heavily on resistance to corrosion of the reinforcement. The resistance is usually adequate, unless significant cracking takes place. In oil storage tanks, cracking may be induced by thermal stress cycles as the tank submerged in cold water is repeatedly filled with warm oil. The corrosion process depends on numerous factors, and predictions are unreliable without a quantitative analysis. A mathematical model of the corrosion process is proposed. The penetration of oxygen, chloride ions, and seawater into the concrete cover is described by diffusion equations. A method for solving the equation system is shown.

Keywords: *corrosion; cracking; mathematical models; offshore structures; seawater; storage tanks; thermal stresses.*

23. Chhauda, J.N. "Nondestructive testing of concrete by the Schmidt rebound hammer", Indian Concrete Journal (Bombay, India); Vol. 50, No. 1, Jan. 1976, pp. 19-20, 28.

During the last two decades, various attempts at developing nondestructive methods of testing concrete have been made, but few have been successful. However, two that have found practical applicability are the ultrasonic method and the surface hardness method using the Schmidt rebound hammer.

Keywords: *compressive strength; concretes; impact hammer tests; nondestructive tests; quality control; statistical analysis; ultrasonic tests.*

24. Connolly, J.P., and Brown, D.M. "Construction tolerances in reinforced concrete beams/joists", ACI Journal, Proceedings; Vol. 73, No. 11, Nov. 1976, pp. 613-617.

This investigation was a pilot study to develop the technique for nondestructive measurement of variations in depth, width, and location of reinforcing steel in existing reinforced concrete beams and joists of 20.3 cm (8 in.) or greater depth. By both optical and electronic measuring devices data were collected on beams and joists chosen from five structures. Statistical evaluation of these data is presented as well as a computer analysis of the approximate effect of such variations on the strength of the members. The results reveal that current as-built structures normally exceed the design-assumed tolerances.

Keywords: *beams; computers; concrete cover; nondestructive tests; pachometers; probability theory; reinforced concrete; reinforcing steels; statistical analysis; tolerances (mechanics).*

25. Davis, S.G. "Further investigations into the strength of concrete in structures", Technical Report No. 42.514, Cement and Concrete Association, London, England; 1976, 20 pp.

At five construction sites the strength of cast-in-place concrete and its variation within and between structural elements have been investigated. The method used to determine the strength was the nondestructive technique of measuring the ultrasonic pulse velocity. This report covers the second part of the investigation; i.e., tests on five different structures with cast-in-place strengths being estimated at up to six months after casting. The first part of the program consisted of tests carried out on about fifty structural members cast during construction of a multistorey building.

Keywords: *age-strength relation; compressive strength; nondestructive tests; structural members; ultrasonic tests.*

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26. Elvery, R.H., and Ibrahim, L.A.M. "Ultrasonic assessment of concrete strength at early ages", Magazine of Concrete Research, London, England; Vol. 28, No. 97., Dec. 1976, pp. 181-190.

Tests were carried out to examine the relationship between ultrasonic pulse velocity and cube strength on concrete from ages of about 3 h over a curing temperature range from 1 to 60°C. It is found that this relationship is practically independent of W/C ratio and temperature but influenced by both aggregate content and type of cement. Strength estimation from pulse velocity was found to be less reliable for velocities less than about 2 km/s than it is for higher velocities. Prediction of the 20-day cube strength from early-age pulse velocity is possible, with limits regarding temperature effects.

Keywords: *age-strength relation; aggregates; cements; compressive strength; nondestructive tests; ultrasonic tests.*

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27. Fagerlund, G. "Approximate method of calculating the drying out process in surface coated concrete slabs on the ground", (in Swedish); CBI Research Report No. 11:76, Swedish Cement and Concrete Research Institute, Stockholm, Sweden; 1976, 34 pp.

The author proposes a relatively simple method of calculating the drying process in concrete slabs under various boundary conditions, such as different surface treatments. In particular, this report calculates the moisture distribution produced under different surface coatings applied to concrete slabs on the ground. The calculations are based on the assumption that the force which causes the transfer of moisture is represented solely by the differences in vapour pressure. The rate of moisture transfer is therefore determined by moisture diffusivity of the concrete. The moisture diffusivity is a function of the relative humidity of concrete.

Keywords: *coatings; concrete slabs; drying; finishes; moisture; moisture content.*

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28. Fertis, D.G. "Concrete material response by acoustic spectra analysis", Proceedings, ASCE; Vol. 102, ST-2, Feb. 1976, pp. 387-400.

The purpose of the research in this paper was to determine material behaviour and strength characteristics of concrete materials by studying stochastically the random-type acoustic emission patterns and intensities that emanate from concrete during loading. The concrete specimens used for this purpose are standard concrete cylinders made up from specific concrete mixtures with definite material properties and strength characteristics. The objective in this research was to develop an experimental setup and recording system that can record the waveform patterns and intensities of these acoustic emissions.

Keywords: *acoustic properties; acoustics; acoustic signals; concretes; cracking (fracturing); probability theory; sound waves; stochastic processes.*

29. Fromm, H.J., and Wilson, G.P. "Cathodic protection of bridge decks: A study of three Ontario bridges", Transportation Record, Transportation Research Board; No. 604, 1976, pp. 38-47.

Many concrete bridge decks are being damaged by surface spalling or internal delaminations caused by corrosion of the reinforcing steel. Cathodic protection was applied to three bridge decks in Ontario, Canada: two slab decks on AASHTO beams and a voided, post-tensioned structure. Each deck was equipped with resistance probes, which showed that the corrosion of the reinforcing steel stopped when cathodic protection was applied. The technique for measuring the polarized potential on the steel was studied. Probes buried in the conductive layer were found to be more effective than half-cell measurements.

Keywords: *bridge decks; bridges (structures); cathodic protection; corrosion; corrosion resistance; field tests; reinforcing steels; spalling.*

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30. Galler, S. "Corrosion testing for replacement of deteriorated concrete", Rural and Urban Roads; Vol. 14, No. 8, Aug. 1976, pp. 21.

A municipal garage floor in New York City became a testing ground for the application of a new technology that uses corrosion of reinforcing bars in concrete to determine the need for rehabilitation. The project, based on chloride level in the top reinforcing bar, proved that such corrosion is an acceptable signal.

Keywords: *chlorides; corrosion; corrosion tests; deterioration; reinforcing steels; repairs.*

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31. Garay, A. "Ultrasonic investigation methods regarding deterioration of concrete in structures damaged by fire", (in Spanish); Informes de la Construccion (Madrid); Vol. 29, No. 286, Dec. 1976, pp. 61-73.

When a building with a reinforced concrete structure catches fire, the members of that structure are affected to a varying degree, depending upon the duration and maximum temperatures of the fire. This article describes a nondestructive method whereby the average calcination depth of the structural members can be calculated by measuring the transmission times of ultrasonic beams through the affected elements. The article ends by proposing suitable considerations and indications for elaborating an electronic calculation program capable of handling the great quantity of data proceeding from a fire of average range.

Keywords: *damage; fire resistance; high temperature; nondestructive tests; reinforced concrete; tests; ultrasonic tests.*

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32. Hachemi, A.A., et al. "Researches on the accelerated corrosion of steels in concrete — Scanning electron microscopy study of the textural evolution at the steel-concrete interface" (in French); Revue des Materiaux de Construction (19 Rue Lafayette, Paris 9e, France); No. 702, May 1976, pp. 285-290.

The use of scanning electron microscopy has allowed the study of morphology and texture of the steel-concrete interface during accelerated corrosion of the material wetted with a saline solution and submitted to an applied electromotive force. Spectacular and particular crystallizations have often been observed inside the binder, and a migration of the corrosion products inside the porosity of the binder around the reinforcement can be noted.

Keywords: *bond (concrete to reinforcement); chlorides; corrosion; corrosion tests; electron microscopy; reinforced concrete; reinforcing steels.*

33. Hirche, D. "IR-spectroscopy, a modern method to test the alkali reactivity of silica aggregates", Proceedings, Symposium on Alkali-Aggregate Reaction-Preventive Measures, The Building Research Institute, Reykjavik, Iceland; 1976, pp. 205-211.

Earlier work in testing methods of alkali silica reactions has been extended to infrared spectroscopy. With IR-spectroscopy, we are able to measure directly the quantity of OH-oscillators on lattice defects or internal interfaces. Measuring the IR intensities of the OH stretching region, the alkali reactivity of silica aggregates can be tested. Silica aggregates with high infrared absorptions are alkali-reactive too.

Keywords: *aggregates, alkali-aggregate reactions; chemical analysis; infrared spectroscopy; silica; siliceous aggregates.*

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34. Jensen, B., and Braestrup, M.W. "Lok-tests determine the compressive strength of concrete", Nordisk Betong (Malmo); Vol. 20, No. 2, 1976, pp. 9-11.

Plastic upper-bound analysis is applied to pullout tests of concrete, assuming a conical failure surface. The modified Coulomb failure criterion is used as a yield condition with an associated flow rule. It is shown that with the application of a suitable annular counterpressure, the pullout force is proportional to the compressive strength.

Keywords: *compressive strength; failure; plastic analysis; pullout tests; tests.*

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35. Lewandowski, R. "Compressive strength of hardened concrete in structures and building members" (in German); Beton Herstellung und Verwendung (Dusseldorf); Vol. 26, No. 12., 1976, pp. 469-475.

This article reviews the various specifications of the German standard DIN 1048 for determination of compressive strength of hardened concrete in structures and building members, from the point of view of the user. Destructive and nondestructive testing incorporated in the standard are explained. Experiences and specifications of other countries are discussed and compared.

Keywords: *compressive strength; concretes; hardened concrete; nondestructive tests; specifications; tests.*

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36. Malhotra, V.M. "Testing hardened concrete: Nondestructive methods", ACI Monograph No. 9, American Concrete Institute/Iowa State University Press, Detroit; 1976, 188 pp.

In this monograph, fundamentals of the methods for the evaluation of hardened concrete are given, testing apparatus explained, and limitations and usefulness noted. Surface hardness and rebound tests, penetration and pullout techniques, and dynamic or vibration tests are described in detail. Radioactive and nuclear methods are described. The magnetic, electrical, microwave absorption and acoustic methods are of limited application and therefore only briefly discussed.

Keywords: *compressive strength; dynamic tests; hardened concrete; impact hammer tests; impact tests; microwaves; modulus of elasticity; moisture content (of aggregate, hardened concrete, etc.); moisture meters; neutron activation analysis; nondestructive tests; penetration tests; pullout tests; radiography; resonant frequency; sonic tests (frequency); sound transmission; ultrasonic tests.*

37. Martinez, M.B. "Correlating strength of test cylinders with Schmidt rebound hammer results (Contribucion al estudio critico del control de calidad de probetas de hormigon de cemento puzolznico mediante ensayos con el esclerometro Schmidt)"; Monografias No. 333, Instituto Eduardo Torroja de la Construccion y del Cemento, Madrid; 1976, 68 pp.

Due to lack of data on the use of the Schmidt rebound hammer evaluation of concrete made with pozzolanic cement and basalt aggregates, commonly used in construction in the Santa Cruz, Teneriffe region a series of tests was conducted to establish a correlation between strengths of cylinders and rebound readings. A range of strength values was established which corresponds to the usual margin in construction concretes. Due to the use of pozzolanic cement, it presents some strength values that are lower than those obtained with normal Portland cement.

Keywords: *basalt; compressive strength; concretes, cylinders; impact hammer tests; pozzolan cements.*

38. McCabe, W.M., Koerner, R.M., and Lord, A.E. "Acoustic emission behaviour of concrete laboratory specimens", Proceedings Vol. 73, No. 7, July 1976, pp. 367-371.

Acoustic emission monitoring of concrete represents a potentially rapid, economic, and reliable method to test full-scale concrete structures nondestructively. Since the technique is relatively new, however, considerable laboratory work of a fundamental nature is required, before field work commences. To this end, a study to monitor the acoustic emissions, which are generated by placing test specimens under load, was initiated. The major findings of this study are reported.

Keywords: *compressive strength; concretes; creep properties; cyclic loads; nondestructive tests; research; sonic tests (resonance); tests; ultrasonic tests.*

39. Osinski, A. "Evaluation of material properties of concrete by dimensionless criteria", Materials and Structures, Research and Testing (Paris, France); Vol. 9, No. 52, July-Aug. 1976, pp. 271-278.

The dependence between the strength of concrete and the sound velocity as well as material density, can be expressed by a dimensionless number of mechanical similitude, denoted by the name of the well-known Polish scientist Bronislaw Bukowski who was working in the field of concrete technology. Instead of strength, the elasticity coefficients can be introduced into the number, since its theoretical basis is the formula of wave velocity in elastic materials. The stability of Bukowski's number is a condition of similitude of the macrostructure of concrete and of the way of testing.

Keywords: *cements; concretes; hydration; microstructure; setting (hardening); ultrasonic tests.*

40. O'Neil, E.F., and McDonald, J.E. "Evaluation of selected instruments used to measure the moisture content of hardened concrete", Technical Report No. C-76-1, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi; 1976, 69 pp.

Six types of gauges for measuring moisture content of hardened concrete were studied to determine their behaviour in long-term service. They were evaluated with respect to stability of measurement and response to moisture change. The results of the test indicate that two gauges (the ionic barrier moisture gauge and the Bouyoucos moisture gauge) reacted the most favourably during the entire 800-day test period. Both types of gauges gave results that were responsive to environmental changes and stable with respect to time.

Keywords: *concretes; measuring instruments; moisture content; moisture meters; test equipment; tests.*

41. Pihlajavaara, S.E. "On practical estimation of moisture content of drying concrete structures" (in Italian and English); Il Cemento (Rome); Vol. 73, No. 3, July-Sept. 1976, pp. 129-138.

The properties of concrete depend on variations of the moisture content. The drying phenomenon of concrete, a complicated composite material more or less unstable during its whole lifetime, is generally so complicated that no single and simple mathematical theory seems to govern its experimental drying features completely. The diffusion theory is mainly used to describe the drying of concrete. On the basis of the simple diffusion theory, the author presents a relatively simple model for the drying process of concrete structures at different relative humidities within the range of 0 to 100% and at different ambient temperatures.

Keywords: *concretes; diffusion; drying; humidity; moisture; moisture content; structures; temperature.*

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42. Rajagopalan, P.R., Jain, V.K., and Rai, M. "Ultrasonic testing of cement mortar subjected to corrosive chemicals", Indian Concrete Journal (Bombay); Vol. 50, No. 7, July 1976, pp. 213-216.

It is important to obtain a correct assessment of the extent of corrosion in cement mortar or concrete caused in aggressive environments such as those in fertilizer plants. For this purpose, a nondestructive method of testing, such as the ultrasonic pulse technique, is to be preferred, since it affords a quick, in-situ method of checking a structure.

Keywords: *chemical attack; corrosion; corrosion tests; flexural strength; mortars (material); nondestructive tests; ultrasonic tests.*

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43. Ramakrishnan, V. "Past and future of concrete quality control", Proceedings, ASCE; Vol. 102, C02, June 1976, pp. 263-276.

This article examines current practice, recent developments, and future prospects of various methods and techniques used for quality evaluation of representative concrete and in-place concrete. Special attention is given to trends that will dominate the field in the future. Recent advances in accelerated test methods, ultrasonic testing, radioactivity methods, probe tests, pullout tests, and rapid analysis of fresh concrete have been reviewed.

Keywords: *accelerated tests; compressive strength; concretes; nondestructive tests; pullout tests; quality control; radiography; ultrasonic tests.*

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44. Schiessl, P. "Regarding the question of admissible crack width and the required concrete cover in reinforced concrete with special consideration of the carbonation of concrete" (in German); Heft No. 255, Deutscher Ausschuss fur Stahlbeton, Berlin; 1976, 175 pp.

In this paper, laws governing the spread of carbonation of concrete and the speed of corrosion of steel in carbonated concrete are discussed, while taking physical characteristics into consideration. The investigations deal with both cracked and uncracked concrete. The thickness of the carbonated layer tends to a limit for both uncracked concrete and crack-free locations. The influence of the crack width and the concrete cover on the corrosion or on the corrosion protection of the reinforcement depends on the carbonation of concrete. On the basis of the results of the tests, the minimum requirements for concrete cover and the necessary limitation of crack width according to DIN 1045 are discussed.

Keywords: *beams (supports); carbonation; corrosion; corrosion resistance; cover; cracking (fracturing); crack width and spacing; reinforced concrete; reinforcing steels; thickness.*

45. Slater, J.E., Lankard, D.R., and Moreland, P.J. "Electrochemical removal of chlorides from concrete bridge decks", Materials Performance, Vol. 15, No. 11, Nov. 1976, pp. 21-26.

A number of potential solutions to the problem are being researched. This article discusses the actual removal of the chloride from the concrete by electrochemical means. Results of laboratory and on-site tests are discussed. The technique is technically feasible, and results of core evaluation and potential tests indicate that reinforcing bars stopped corroding after the electrochemical treatment.

Keywords: *bridge decks; bridges (structures); chemical cleaning; chlorides; corrosion; deicers; deterioration; reinforcing steels; research; salts; spalling.*

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46. Suchan, M. "Nondestructive corrosion test method for prestressing cables" (in Polish); Archiwum Inzynierii Ladowej (Warsaw); Vol. XXII, No. 2, 1976, pp. 321-332.

The theoretical basis of the nondestructive method to measure the corrosion of reinforcing steel is described. It consists of the measurements of the potential distribution along the bars and of the resistance distribution in the bar cover. The anode places are then found numerically together with relative intensity of corrosion. Some results of the measurements on actual structures are given to assess the applicability of this method to testing the conditions of reinforced concrete and prestressed structures.

Keywords: *corrosion; corrosion resistance; corrosion tests; nondestructive tests; prestressing steels; reinforcing steels.*

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47. Van der Winden, N.G.B. "Research into bonding and setting phenomena of concrete mortar by means of ultrasonic vibrations" (in Dutch); Cement (Amsterdam); Vol. 28, No. 8, Aug. 1976, pp. 357-361.

Measurements by means of ultrasonic vibrations passing through hardened concrete have been used for some time, as opposed to such measurements through fresh concrete mortar. Results obtained from ultrasonic measurements indicate the composition of the concrete mortar to be used as well as the dosage of additives. The present article provides not only a discussion of the way in which the measurements were carried out but also various results of research in the matter.

Keywords: *heat of hydration; mortars (material); retardants; setting (hardening), ultrasonic tests; water-cement ratio.*

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48. Weber, W.G. Jr., Grey, R.L., and Cady, P.D. "Rapid measurement of concrete pavement thickness and reinforcement location: Field evaluation of nondestructive systems", NCHRP Report No. 168, Transportation Research Board, Washington, D.C.; 1976, 63 pp.

This research project was initiated to develop alternatives to the current method of determining pavement thickness and reinforcement location by coring. Coring is time-consuming, costly, destructive, and of no use in quality control during construction. Furthermore, existing acceptance criteria, dictated by the limitations inherent in coring, are widely diverse and generally lack a precise statistical basis.

Keywords: *concrete cores; concrete pavements; cover; field tests; measuring instruments; nondestructive tests; pachometers; quality control; reinforcing steels; research; sampling; thickness; ultrasonic tests.*

1977

49. Aronsson, R., Fagerlund, G., and Larsson, B. "Impact strength of concrete piles" (in Swedish), CBI Rapporter No. 1:77, Swedish Cement and Concrete Research Institute, Stockholm; 1977, 69 pp.

This report discusses the results of tests on pile-driving in Sweden. A compilation and analysis of earlier studies on impact strength of concrete is included with a general analysis of the problem of concrete for piles. Developments in testing methods, by which the impact strength of concrete subjected to stress-waves of the type occurring during pile-driving can be accurately measured, are also discussed. The test method, which seems promising, will be used for more comprehensive studies in the future.

Keywords: *concrete piles; impact strength; impact tests; pile-driving.*

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50. Bellander, Ulf. "Concrete strength in finished structure, Part 2: Non-destructive testing methods — Inventory of literature", (in Swedish); CBI Rapporter No. 2:77, Swedish Cement and Concrete Research Institute, Stockholm; 1977, 108 pp.

Through an inventory of literature, the present knowledge of testing compressive strength in finished structures by NDT methods has been reviewed. It is concluded that nondestructive testing (NDT) methods can be used to determine the compressive strength and modulus of elasticity, after empirical relationships have been established. The combined method, using ultrasonic pulse velocity (UPV) and the rebound number, is considered the most accurate to estimate the compressive strength of finished structures. The influence of various factors on the measurement value for NDT methods is summarized in a table.

Keywords: *compressive strength; concrete; core; nondestructive testing (NDT); rebound hammer; pullout method; ultrasonic pulse velocity (UPV).*

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51. Bellander, Ulf. "Concrete strength in finished structure, Part 3: Non-destructive testing methods — Investigations in laboratory and in-situ", (in Swedish); CIB Rapporter No. 3:77, Swedish Cement and Concrete Research Institute, Stockholm; 1977, 226 pp.

Various nondestructive testing (NDT) methods for determining the compressive strength on in-situ structures have been tested in laboratory and on building sites. The tested methods are the completely NDT method; testing by UPV; testing with Schmidt rebound hammer (Type N); combined testing, using both these methods; limited destructive method and pullout testing. The values measured have been related to and compared with the compressive strength of specimens from drilled cores from structures.

Keywords: *combined nondestructive methods; concrete; Schmidt test hammer; ultrasonic pulse velocity.*

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52. Browne, R.D., Domone, P.L., and Geoghegan, M.P. "Inspection and monitoring of concrete structures for steel corrosion", Offshore Technology Conference, Proceedings, Vol. 1, Dallas, Texas; 1977, pp. 571-580.

Keywords: *reinforcing steels; corrosion; prestressed concrete; nondestructive testing; monitoring corrosion.*

53. Cady, P.D., Kline, D.E., and Blankenhorn, P.R. "Deep sealing of concrete bridge decks with linseed oil and related compounds", Report No. FHWA-77-75-4, Pennsylvania Transportation Institute, Pennsylvania State University, University Park; 1977, 103 pp.

One means of preventing or retarding reinforcement corrosion is to impregnate concrete with a suitable material to prevent ingress of deicing salts. The major thrust of the research described in this report is to evaluate linseed oil and related compounds as concrete impregnants to prevent or significantly retard reinforcing bar corrosion and to develop and demonstrate techniques suitable for achieving bridge deck impregnation. Laboratory investigations reveal that about 50-50 mixture (by weight) of boiled linseed oil and mineral spirits optimizes the trade-off between depth of impregnation and sealing properties. Also, impregnation of nonsalt-contaminated concrete reduces chloride penetration by a factor of about 10 for impregnation depths of the magnitude given above.

Keywords: *bridge decks; corrosion; deicers; impregnating; linseed oil; plastics; polymers and resins; protective coatings; sealers; sealing.*

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54. Chabowski, A.J., and Bryden-Smith, D. "Simple pull-out test to assess the in-situ strength of concrete", Precast Concrete (London); Vol. 8, No. 5, May 1977, pp. 243-246, 258.

The objective of the research described in this paper was to produce a simple test, causing little disruption, to provide direct information on the strength of high-alumina cement concrete in prestressed, X-shaped beams produced under factory-controlled conditions. A pullout test based on the correlation between compressive strength of concrete and the forces in a wedge anchor needed to produce internal cracking in concrete was developed. The test method and the research leading to its application are described.

Keywords: *cracking (fracturing); compressive strength; high-alumina cements; prestressed concrete; pullout tests; research; tests.*

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55. Clemena, G.G., Reynolds, J.W., and McCormick, R. "Gran method of endpoint determination in chloride analysis by potentiometric titration", Transportation Research Record No. 651, Transportation Research Board; Washington, D.C.; 1977, pp. 1-6.

The Gran method of endpoint determination can replace the currently used first-derivative method in the potentiometric titration procedure for the analysis of chloride in hardened concrete. This modification improves the procedure by (a) circumventing the frequently encountered difficulty of determining the endpoint, a difficulty that arises from unstable electrode potentials, (b) eliminating the need to spike solutions of low-chloride concrete samples with a known amount of chloride before titration, (c) enabling the titration to be performed more quickly, and (d) improving the overall precision and accuracy.

Keywords: *bridge decks; chemical analysis; chlorides; corrosion; titration.*

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56. Davis, S.G. "Effect of variations in the aggregate content of concrete columns upon the estimation of strength by the pulse-velocity method", Magazine of Concrete Research (London); Vol. 29, No. 98, Mar. 1977, pp. 7-12.

This article reports results of a series of tests planned to place quantitative limits upon the accuracy of the ultrasonic pulse-velocity method, when it is used to assess the variations in strength through the height of a lift of concrete. Changes in the mix proportions of the concrete resulting from the placing process have been monitored, and the effect of such changes upon the correlation between strength and pulse velocity investigated. The results suggest that, for a typical structural concrete mix, the error in the estimation of the variability of strength is likely to be in the range of 4.5 to 9%.

Keywords: *aggregates; columns (supports); mix proportioning; nondestructive tests; ultrasonic tests.*

57. Cosmulescu, P. "Review on some approaches of strength-density relation in concrete from gamma ray testing point of view", Buletinul Institutului Politechnic Din Iasi (Bulletin of the Polytechnic Institute of Jassy), Section V, Construction, Architecture; Vol. XXIII, No. 1-2, 1977, pp. 49-53.

The nondestructive methods for testing concrete are currently preferred on building sites and in precast concrete factories. The density of concrete can be measured nondestructively with gamma radiation. To decide whether the measurement of density could be used to give a reasonably accurate value of the strength of concrete, the sensitivity of the strength of concrete to change in the density must be known. Also, it is important to recognize that the radioisotope method of testing a concrete specimen does not measure its strength.

Keywords: *air entrainment; compressive strength; concrete; density; gamma radiation; nondestructive tests.*

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58. Forrest, J.B. "In-situ measuring techniques for pile length", Final Report TN-1475, Civil Engineering Laboratory, Port Hueneme; 1977, 26 pp.

Two techniques were evaluated for determining in-situ the length of sheet piles. One is based upon the reflection of sonic energy, and the other upon sensing the electromagnetic flux field that builds up around ferrous objects in the earth's magnetic field. The sonic technique was found to operate satisfactorily, within limits, on piles made of steel, concrete, and wood, either with tops exposed or with tops encased in a concrete decking. The electromagnetic flux-sensing method involves inserting a probe into the soil in the vicinity of the pile for locating tip.

Keywords: *concrete piles; electromagnetic radiation; foundations; measuring instruments; nondestructive tests; piles; ultrasonic tests.*

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59. Fromm, H.J. "Cathodic protection of rebar in concrete bridge decks", Materials Performance, National Association of Corrosion Engineers (P.O. Box 986, Katy, Texas 77450); Vol. 16, No. 11, Nov. 1977, pp. 21-29.

The problem of corrosion of steel in reinforced concrete bridge decks is outlined. Cathodic protection to halt this corrosion has been applied to four bridge decks in Ontario, and the techniques used are described. Both slab decks on beams and a post-tensioned deck were protected. The distribution of electric power across the decks was studied, and the best configuration of anodes to deliver the power was determined. Two types of electrically conductive mix are described. The methods of detecting the polarized voltage on the steel were studied, and the successful system is described.

Keywords: *bridge decks, cathodic protection; corrosion; corrosion resistance; reinforcing steels.*

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60. Hasija, V., and Angeloff, C. "Concrete-deck deterioration: Concrete-filled steel-grid bridge decks have the answer", Transportation Research Record No. 651, Transportation Research Board, Washington, D.C.; 1977, pp. 11-16.

The most common cause of bridge deck distress is the corrosion of the reinforcing steel that results from the intrusion of chlorides into the concrete after repeated deicer applications. However, many concrete-filled steel-grid bridge decks in existence have not been affected by deicing chemicals, although the amount of chloride present is significant and sufficient to initiate steel corrosion. Data on more than about 400 000 m^3 (4 000 000 ft^3) of grid decks built between 1931 and 1969 showed that the performances of such decks have been excellent.

Keywords: *bridge decks; composite construction (concrete and steel); corrosion; corrosion resistance; metal deck forms; reinforcing steels.*

61. Giron, S.V., and Martialay, R.M. "Permeability of concrete piping liners" (in Spanish); Monography No. 344, Instituto Eduardo Torroja de la Constuccio y del Cemento (Madrid); Sept. 1977, 71 pp., 300 ptas.

The experimental work carried out with the objective of establishing a test method for determining the degree of water permeability of concrete piping liners, destined to supply water to towns, is studied.
The study includes the design of a permeability meter which permits its coupling to any pipe generator either in a vertical or horizontal position.

Keywords: *concrete pipes; permeability; pipelinings; pipes (tubes).*

62. Hansen, P.F., and Pedersen, E.J. "Maturity computer for controlled curing and hardening of concrete" (in Swedish); Nordisk Betong (Malmo); Vol. 21, No. 1, Jan. 1977, pp. 21-24.

With a maturity computer it is possible to follow the hardening of the concrete in a structure and at the same time reliably carry out individual operations such as insulation, stripping of forms, covering, and tensioning. This computer calculates and displays the maturity of the concrete, the rate of increase of maturity per hour, and the degree of hardening reached in relation to a predetermined maturity.

Keywords: *computers; curing; form removal; formwork (construction); setting (hardening).*

63. Kasperkiewicz, J. "Fibre spacing in steel fibre reinforced composites", RILEM Bulletin; Vol. 10, No. 55, Jan.-Feb. 1977, pp. 25-31.

A method is presented to evaluate the fibre content or to estimate the distribution of fibres in steel-fibre-reinforced composite materials from X-ray analysis. The basic notion in this method is an apparent fibre-spacing defined as the average spacing between the intersections of individual fibre projections upon a certain plane and an arbitrary base line drawn on that plane. Such apparent spacing may be estimated analytically, and may also be measured directly on the radiogram. The comparison between analytical and experimental data shows satisfactory agreement.

Keywords: *composite materials; fibre reinforced concretes; fibres; metal fibres; nondestructive tests; X-ray analysis.*

64. Komloš, K., Kruml, F., and Homolka, Z.D. "Judgment of concrete quality in transportation structures", Transportation Research Record No. 652, Transportation Research Board, Washington, D.C.; 1977.

This paper deals with judgment of the quality of fresh and hardened concrete used in transportation structures in Czechoslovakia.
For hardened concrete, destructive and nondestructive methods of testing concrete properties are analyzed and evaluation techniques are given. The judgment of the acceptability of fresh concretes in relation to their composition and workability is analyzed. Sclerometric and acoustic methods of nondestructive testing are discussed. Statistical evaluation is emphasized.

Keywords: *acceptability; fresh concretes; hardened concretes; nondestructive tests; quality control; tests.*

65. Malhotra, V.M. "Contract strength requirements — Cores versus in-situ evaluation", ACI Journal, Proceedings; Vol. 74, No. 4, Apr. 1977, pp. 163-172.

The present-day building codes allow acceptance of concrete on the basis of the 28-day compressive strength of test specimens cured under standard conditions. The unsatisfactory nature of the existing acceptance procedure is brought out, and a case is made for the abandonment of the existing acceptance procedures in favour of a new approach. The suggested procedure consists of three steps: first, it is ensured that concrete delivered to the site meets specification requirements; second, accelerated strength testing is used for acceptance testing; third, emphasis is placed on in-situ testing of hardened concrete using such methods as the pullout, penetration resistance, hardness, and pulse velocity tests.

Keywords: *accelerated tests; acceptability; building codes; compression tests; compressive strength; concrete cores; curing; cylinders; field tests; fresh concretes; hardened concretes; nondestructive tests; penetration tests; pullout tests; quality control; reinforced concrete; reinforcing steels; samples; specifications; specimens; ultrasonic tests.*

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66. Markestad, A. "Investigation of concrete in regard to permeability problems and factors influencing the results of permeability tests", Cement and Concrete Research Institute (N-7034, Trondheim-NTH, Norway); 1977, 278 pp.

The purpose of this work was primarily to establish a new permeability-testing procedure to replace the air pressure and tap water method which has proven inadequate. The use of distilled water, which absorbs more of the air in the concrete specimens than the tap water, was found to be effective. Concrete specimens in various shapes, thicknesses, and surface conditions were studied. Other factors investigated were: (1) curing conditions; (2) age at start of exposure; (3) cement content and fineness; (4) aggregate gradation; and (5) admixtures.

Keywords: *alkalinity; concretes; lime; permeability; specimens; water content.*

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67. Nielsen, J., and Griffin, D.F. "Acoustic emission of plain concrete", Journal of Testing and Evaluation; Vol. 5, No. 6, Nov. 1977, pp. 476-483.

When a specimen of engineering material is subjected to external loads, stress waves, known as acoustic emissions, are induced. A unique characteristic of many materials that emit acoustical energy is, that upon reloading the specimen does not emit acoustical energy until the magnitude of loading exceeds the prior maximum loading. This investigation was undertaken to determine whether this characteristic could be used to disclose the loading history of plain portland cement concrete. The test results show that the unique characteristic is very temporary and therefore cannot be used to determine the prior maximum loading on a concrete specimen. Within a matter of hours, concrete subjected to loading within its elastic limit recovers, and acoustical energy may again be released by reloading.

Keywords: *acoustic properties; concretes; loads (forces); plain concrete; research; tests.*

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68. Nilsson, L.O. "Moisture problems at concrete floors", Report TVBM-3002, 1977, 188 pp. (available from Svensk Byggtjanst, Box 1403, S-11184 Stockholm, Sweden).

Often, damage to floor finishes occurs because of excessive moisture in the underlying concrete slab. The causes of this are either from incomplete drying of the concrete or from moisture entering the floor construction. Watertight floor finishes become detached and form bubbles; floors constructed out of wood-based materials can become hazardous. This summary discusses results, experiences, and ongoing research. A measuring method, which is being developed, is also described (Swedish Building Research Summaries, No. 1, 1979, S25).

Keywords: *concrete finishes (hardened concrete); damage; floors; moisture.*

69. Niyogi, S.K., and Mukhopadhyay, M. "Ultrasonic pulse testing of some field structures", Indian Concrete Journal, (Bombay); Vol. 51, No. 5, Apr. 1977.

The results of ultrasonic pulse method of testing five field structures are presented in the paper. The need for carrying out the tests is discussed, and the pulse technique including the acceptance criteria is briefly reviewed. The paper stresses the importance of ultrasonic testing as a supporting or follow-up investigation.

Keywords: *Field tests; nondestructive tests; ultrasonic tests.*

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70. Rajagopalan, P.R., Jain, V.K., and Rai, M. "Ultrasonic testing of concrete specimens attacked by aggressive chemicals", Indian Concrete Journal (Bombay); Vol. 51, No. 7, July 1977, pp. 212.

It is sometimes difficult to gauge the extent of corrosion of concrete exposed to aggressive chemicals, as found, for example, in fertilizer plants or chemical factories. Since the ultrasonic pulse technique is being increasingly used for nondestructive testing of concrete, an attempt has been made to correlate the pulse velocity and strength of concrete specimens exposed to aggressive chemical solution of varying concentrations for different curing periods. In most cases, linear correlations were obtained, with the strength being predicted within an error of ±20%.

Keywords: *chemical attack; concretes; corrosion; flexural strength; nondestructive tests; ultrasonic tests.*

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71. RILEM. "Recommendations for testing concrete by hardness methods", Bulletin, Materials and Structures, Research and Testing (Paris); Vol. 10, No. 59, Sept./Oct. 1077, pp. 313-316.

These recommendations are an attempt at producing a guide to the usefulness of the hardness testing methods to delineate the areas of application, to point out sources of inaccuracy, and to give guidance for the calibration of hardness devices in a laboratory as well as guidance for their use on a structure. These recommendations do not give guidance for the interpretations of results.

Keywords: *impact hammer test; nondestructive tests; test equipment; tests.*

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72. RILEM. "International symposium on testing in-situ of concrete structures" (in French and English); Proceedings of RILEM Symposium, held in Budapest, Sept. 1977, Two volumes. Order from OMKDK-Technoinform (H-1428 Budapest, POB 12, Hungary).

The Symposium dealt with some factors connected with testing in-situ of concrete structures, especially with the interaction of theory and testing in-situ, load tests, long-term observation of structures, and experimental measuring methods and instrumentation.
The 63 lectures and discussions are published in two volumes of more than 800 pages total.

Keywords: *bridges (structures); field tests; load tests (structural); nondestructive tests; reinforced concrete.*

a) Batizi, A., and Kelemen, L., Building Trade Consultation Service on Anti-Corrosion Protection, Budapest, Hungary, "The possibilities of structure examination by thermovision", pp. 193-204.

The following 7 papers were published in Proceedings, Vol. 2, Session IV.:
The thermovision infra-technical examination process is suitable for investigating any phenomena involving thermal radiation or changes in thermal radiation. Thus, highly valuable information can be obtained about an object subjected to examination, particularly about its built-in structural components. A great advantage of the method is that it furnishes results at a fast rate and without any destruction.

b) Borjan, J., Dept. of Building Material, Technical University, Budapest, "Inhomogeneity in structural concrete and its nondestructive determination", pp. 205-213.

The effect of concrete technology parameters on strength, nondestructive characteristics, and their relations intervening in nondestructive strength assessments are considered. The research program involved a complete nine-factored test, involving all possible combinations of all levels of test parameters. Test cubes have been tested for Schmidt rebound hardness, ultrasonic velocity and ultimate compressive strength.

c) Dayaratnam, P., Indian Institute of Technology, Kanpur, India, Ranganathan, R., Regional Engineering College, Calicut, India, "Non-destructive testing of fly-ash concrete in-situ and statistical analysis", pp. 229-235.

The paper presents nondestructive testing of fly-ash concrete of strength up to 150 kg/cm^2. This concrete was used in a dam. After several months of casting of concrete, nondestructive testing with a concrete test hammer was conducted. Several thousands of readings have been evaluated by statistical analysis using IBM 7044 calculator and presented as histograms. The results are compared with the cube tests, and the safety of the structure is evaluated.

d) Johansen, R., University of Trondheim, Trondheim-NTH-Norway, "A new method for the determination of in-place concrete strength at form removal", pp. 276-288.

The paper describes a new Norwegian method for the determination of the concrete strength in the structure, especially at the time of form removal. The working principle of the test is to measure the flexural strength in plane sections located parallel to, and at a certain distance from, the concrete surface. These sections are established by the use of special forms inserted in the concrete. The results show that the correlation with conventional compressive strength is satisfactory, and the economy and rapidity of the method is emphasized.

e) Pohl, E., Technische Hochschule Leipzig, DDR-703, Leipzig, "Quality control in buildings by means of nondestructive test procedures", pp. 312-324.

The paper gives some practical examples for nondestructive testing methods developed for the determination of structural parameters of concrete structures: ultrasonic detection of crack depth, testing of structural disturbances in prestressed concrete structures by ultrasonic method, analysis of sound emission, and detection of location of holes in main girders by means of gamma rays. In-situ tests of structures supply basic data for calculations, control, and regulations.

f) Sammal, O., and Eesorg, H., Building Research Institute of the Estonian SSR, Tallin, "Concrete stress meter", pp. 325-334.

The ambiguous dependence of stresses on strains in concrete (due to shrinkage, creep, microcracks, etc.) excludes the possibility of accurate determination of stresses by means of results from strain measurements. The use of the new measuring devices, the so-called measuring slabs, allows the reliable direct measurement of stresses and a more detailed study of the actual behaviour of concrete.

g) Stehno, G., and Mall, G., University of Innsbruck, A-6020 Innsbruck, Austria, "The tear-off method — a new way to determine the quality of concrete in structures on site", pp. 335-347.

A study of use of tear-off method to determine the quality and homogeneity of concrete in finished structures on site. The proposed testing technique is being critically examined and its significance rated as a basis for a novel tear-off testing apparatus. The tests carried out with it were aimed at judging whether it would be possible, by tearing off testing plates glued onto concrete surfaces, to find a reproducible and usable correlation between concrete quality and tear-off force or tear-off strength in each particular instance.

73. Toke, T., Okada, K., and Kamiyama, Y. "Some experiments on the permeability of concrete" (in Japanese), Takenaka Technical Research Report No. 18, Takenaka Technical Research Laboratory (5-14, 2-chome, Minamisuna, koto-ku, Tokyo, Japan); 1977, pp. 74.

In the construction of liquid-retaining structures, unsatisfactory watertightness of concrete causes leakage and affects the durability of the structures. This experimental study discusses the permeability of concrete structures mainly from the point of view of practical execution, by using the results of permeability and strength tests on 75 cylindrical specimens from a model water storage tank. Results of compressive strength and tensile strength tests and the effects of drying and shrinkage are also studied.

Keywords: *compressive strength; concretes; permeability; tensile strength.*

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74. Thornton, H.T. "Development of procedures for nondestructive testing of concrete structures; Report 1, Present practices", Miscellaneous Paper No. C-77-11, U.S. Army Waterways Experiment Station, Vicksburg; 1977, 17 pp.

The Concrete Laboratory (CL) of the U.S. Army Engineers Waterways Experiment Station has used nondestructive testing (NDT) in the evaluation of concrete and concreting materials since the creation of the CL (1946). In recent years, more emphasis has been placed on the inspection and structural evaluation of completed structures by the Corps of Engineers. The need for a capability to predict, prior to placement, certain properties of concrete mixtures after hardening has been identified. This report discusses the history, progress to date, and needs for future research and development in the field of NDT.

Keywords: *dynamic tests; nondestructive tests; petrography; research; resonant frequency; ultrasonic tests; X-ray diffraction.*

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75. Van der Winden, N.G.B., and Brant, A.W. "Ultrasonic testing for fresh mixes", Concrete (London); Vol. 11, No. 12, Dec. 1977, pp. 25-28.

The specifications for concrete for offshore platforms in the North Sea are rigorous, not only for strength, but also for durability and watertightness. The need to place large volumes of high-quality concrete very quickly means that a close check on all properties of concrete must be kept even during placing, so that additives and mixes can be regulated as necessary. During building of the Dunlin A platform for Shell UK, ANDOC successfully used ultrasonic testing to give an early indication of the properties of the concrete. This article describes the ultrasonic test equipment and procedures used in the project.

Keywords: *fresh concretes; nondestructive tests; offshore structures; quality control; test equipment; ultrasonic tests.*

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76. Weltman, A.J. "Integrity testing of piles: a review", Report No. PG4, Construction Industry Research and Information Association, London; 1977, 36 pp.

This review discusses defective concrete piles and integrity testing as opposed to traditional load testing. The contractual aspects of the introduction of integrity testing on sites are considered fully. The currently available tests are described under the headings of various overriding principles. Some methods of testing now at the research stage are included. Detailed requirements of the tests are summarized in tabular format and approximate costs are given where possible.

Keywords: *concrete piles; dynamic tests; foundations; loads (forces); nondestructive tests; piles; radiography; research; test equipment; tests.*

1978

77. Andrade, C., and Gonzalez, J.A. "Prediction of potential corrosivity of concrete additives by the joint determination of pitting potential and polarization resistance" (in Spanish and English); Research Working Paper No. 33, Instituto Eduardo Torroja de la Construccion y del Cemento, Madrid; 1978, 45 pp.

A brief theoretical review is given of the electrochemical methods currently in use to evaluate either the susceptibility of reinforcement steel to localized attack or its instantaneous corrosion rate. Results of $Ca(OH)_2$-saturated solution and mortar tests on the corrosion effects of concrete additives are reported.

Keywords: *admixtures; chemical attack, corrosion; corrosion resistance; electrochemical corrosion; reinforced concrete; reinforcing steels.*

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78. ASTM Special Technical Publication. "Significance of tests and properties of concrete and concrete-making materials", No. 169 B, American Society for Testing and Materials, Philadelphia; 1978, 882 pp.

This publication is a revision and expansion of the ASTM report on "Significance of Tests and Properties of Concrete and Concrete-Making Materials", published in 1966. The present report covers several types of materials not referred to in earlier reports but whose importance has increased since the 1966 report. The book, divided into four parts, presents current views.

Keywords: *admixtures; aggregates; alkali-carbonate reactions; cellular concretes; concrete technology; concretes; mix proportioning; nondestructive tests; properties; pumping; sampling; statistical analysis; tests.*

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79. Bellander, U. "Strength in concrete structures", Rapporter No. 1:78, Swedish Cement and Concrete Research Institute, Stockholm; 1978, 15 pp.

It is well known, but normally not anticipated in national codes, that the compressive strength is lower in structure than in standard specimens. To judge the load-bearing capacity, the actual measured strength is used. Strength losses may occur in the structures: 15% and more due to bad curing; 30 to 50% due to early freezing, and 60% due to bad compaction. Vacuum treatment, however, normally improves the strength. Tests of drilled-out cores are regarded as the most accurate testing method. Other testing methods were ranked in order of accuracy: pullout method, combined Swedish NDT method, Schmidt rebound method, and ultrasonic pulse velocity method.

Keywords: *compressive strength; concrete cores; nondestructive tests; pullout tests; reinforced concrete; structures; tests; ultrasonic tests.*

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80. Chou Chen, L., and Katz, D.L. "Diffusion of methane through concrete", ACI Journal, Proceedings; Vol. 75, No. 12, Dec. 1978, pp. 673-679.

Data have been taken on the diffusion rate of methane through concrete at atmospheric conditions. Diffusion rates were measured for both dry concrete and water-saturated concrete. Permeability and threshold pressure have been used as parameters for governing the diffusion characteristic of concrete. Knowing the permeability of concrete, one can compute the rate at which gases will diffuse through it.

Keywords: *concretes; diffusion; diffusivity; methane; permeability; porosity.*

81. Chung, H.W. "Appraisal of the ultrasonic pulse technique for detecting voids in concrete", Concrete (London); Vol. 12, No. 11, Nov. 1978, pp. 25-28.

This article discusses ultrasonic testing as a simple, non-destructive, and reasonably accurate method of detecting deep-seated voids or honeycombed patches in concrete members. Experimental test results, statistical analysis, and conclusions are included.

Keywords: *concretes; tests; ultrasonic tests; voids.*

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82. Clemena, G.G., and McKeel, W.T. Jr. "Detection of delamination in bridge decks with infrared thermography", Transportation Research Record No. 664, Transportation Research Board, Washington, D.C.; 1978, pp. 180-182.

The use of infrared thermography to define variations in surface temperatures accurately was evaluated as a means of defining delaminated areas caused by corrosion of reinforcing steel in concrete bridge decks. In a comparative study of infrared thermography and conventional deck evaluation techniques, including the sounding of the surface with a hammer and chain drag and the use of a rolling delamination detector, all were found generally satisfactory. However, the infrared thermography procedure proved advantageous in disclosing incipient delaminations, those in which the cracking is confined to the close vicinity of the reinforcing steel, and in providing detailed records of the separated areas.

Keywords: *bridge decks; bridges (structures); corrosion; delaminating; infrared systems; thermography.*

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83. Davis, S.G. "Ultrasonic pulse velocity testing of concrete", Proceedings, Australian 7th National Conference on Nondestructive Testing", Adelaide, Australia; Aug. 28-31, 1978, pp. 103-119. Publ.: Australian Institute for NDT, Kalamunda, WA 6076, Australia.

The background and theory of technique, the equipment required and the test procedures for the assessment of strength and elastic modulus of reinforced concrete are discussed. Reference is made to the advantages and limitations of the method.

Keywords: *ultrasonic testing; reinforced concrete, nondestructive testing; reinforcing steels.*

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84. Deacon, R.C. "Watertight concrete construction", Publication No. 46. 504, Cement and Concrete Association, London; 1978, 31 pp.

This booklet highlights the factors that a designer should consider when preparing a design for a watertight structure and the practical problems which must be foreseen by those on site concerned with the supervision and actual construction. The chapter on design deals with design for thermal and moisture movements, roof slabs, and joints. The final chapter discusses jointing materials and linings.

Keywords: *admixtures; concrete construction; joints; linings; mix proportioning; permeability; structural design; water tanks.*

85. Dufay, J.C. "Television inspection system using high-energy radiation nondestructive testing in prestressed concrete bridges", Proceedings, 1st European Conference on Nondestructive Testing, Vol. 3, Mainz, Germany; 24-26 Apr. 1978, pp. 545-552. Published by: Deutsche Gesellschaft fur Zerstorungsfreie Prufing, Berlin, BRD.

The principal problem in checking prestressed concrete structures of bridges, solved during the study of a chain of television radiography, was that of the high-energy photons/gamma-photons converter. An increase in the maximum thickness of investigated concrete structures to 45 cm is anticipated.

Keywords: *prestressed concrete; nondestructive testing; television; radiation tests; radiography.*

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86. Hundt, J., and Wagner, A. "Effects of moisture content and maturation on the thermal conductivity of concrete" (Einfluss des Reifgrades auf die warmeleitfahigkeit von Beton), Heft 297, Deutscher Ausschuss fur Stahlbeton, Berlin, BRD; 1978, pp. 3-23.

In a research program, attention was given to the investigation of thermal conductivity and diffusivity (which depend upon moisture content, temperature, and age of concrete). Measurements were carried out by means of a non-steady state (heating wire) method on samples of concrete. The values of the thermal conductivity and diffusivity were calculated from the measured temperature/time function, correlated to the cited parameters.

Keywords: *age; aggregates; concretes; moisture; moisture content; temperature conductivity; thermal diffusivity.*

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87. Litvin, A., and Belliston, H.W. "Sound transmission loss through concrete and concrete masonry walls", ACI Journal, Proceedings; Vol. 75, No. 12, Dec. 1987, pp. 641-646.

Many building codes require minimum sound transmission loss values, expressed as sound transmission class (STC), of 45 to 50. Tests of sound transmission loss were made on 203-mm (8-in.) thick concrete masonry walls and on 152- (6-in.) and 203-mm (8-in.) thick cast concrete walls. These walls were finished with materials intended to increase their sound transmission loss. Using furring, acoustic insulation, and wallboard attachments, STC values up to 59 were obtained for the masonry and 63 for cast concrete walls.

Keywords: *acoustic properties; building codes; concrete panels; furring; masonry walls; noise reduction; residential buildings; sound transmission; wallboard; walls.*

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88. McDonald, J.E., and Liu, T.C. "Concrete for earth-covered structures", Miscellaneous Paper C-78-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg; 1978, 26 pp.

Low permeability to water is a primary consideration in the design and construction of earth-covered concrete structures. Factors affecting the permeability of concrete are generally classified into three groups: (1) constituent materials; (2) methods of concrete preparation; and (3) subsequent treatment of the concrete. Some specialized concretes include polymer-impregnated concrete, polymer concrete fibre-reinforced concrete, and ferrocement.

Keywords: *ferrocement; fibre-reinforced concrete; permeability; polymer-portland cement-concrete; protective coatings; subsurface structures.*

89. Reynolds, W.N., Wilkinson, S.J., and Spooner, D.C. "Ultrasonic wave velocities in concrete", Magazine of Concrete Research (London); Vol. 30, No. 104, Sept. 1978, pp. 139.

The elastic constants of wet and dry concrete specimens of known composition have been calculated from those of cement paste, water, and two types of aggregate by using a theoretical model built by Boucher. The densities were also calculated, and the velocities of three types of ultrasonic wave were obtained. It was shown that the calculated velocities are in satisfactory agreement with those measured on some typical concretes. The suitability of gamma radiometry as a measure of density was also assessed by the measurement of mass absorption coefficients on all the materials involved.

Keywords: *concretes; density; gamma rays; modulus of elasticity; nondestructive tests; ultrasonic tests; wetting and drying tests.*

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90. Stewart, J.C. "Internally sealed concrete: Wax beads", Report No. FHWA-RD-OK-79-02-1, Oklahoma Dept. of Transportation (Research and Development Division, 200 N.E. 21st ST., Oklahoma City, Okla.); 1978, 39 pp.

This report covers the placement, heating, and testing of two test sites: a salt-shed floor, and a bridge deck span. Wax beads were mixed with fresh concrete and used as a 38-mm (1.5-in.) overlay on the salt house floor slab. In the construction of the bridge span, wax beads were used throughout the full 240-mm (9.5-in.) depth of the deck to avoid two-stage placing. Various tests were run on the slabs. Discussed in this report are: (1) absorption, (2) penetration, (3) chloride analysis, (4) skid resistance, (5) crack survey, (6) compressive strengths, and (7) half-cell.

Keywords: *absorption; bridge decks; concretes; floors; heating; penetration tests; resurfacing; sealing; skid resistance; tests; waxes.*

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91. Swamy, R.N., Editor, RILEM Symposium 1978. "Testing and test methods of fibre cement composites", Construction Press Ltd., Lancaster; 1978, 545 pp.

This volume contains papers about concrete testing and test methods of fibre cement composites presented at the 1978 RILEM International Symposium held at the University of Sheffield, England. The contents of this reference book include information on: general testing, quality control, and rheology; fracture and impact testing; shrinkage, moisture movement and density; testing, fatigue, and shear; fibre distribution and orientation; fibre-matrix interfacial bond; mechanical testing for tension and durability; nondestructive testing; and compression and flexure.

Keywords: *bond (concrete to reinforcement); composite materials; compressive strength; cracking (fracturing); density; durability; fatigue; fibre-reinforced concretes; fibres; flexural strength; nondestructive tests; pullout tests; reinforcing steels; shrinkage; tensile strength.*

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92. Vassie, P.R. "Nondestructive evaluation of the corrosion of concrete reinforcement by chlorides", Proceedings, Conference on Corrosion of Steel Reinforcement in Concrete Construction, London; Feb. 1978, pp. 57-78.

A number of nondestructive methods for measuring and detecting the corrosion of mild steel in alkaline media have been investigated. The alkaline media used were (a) calcium hydroxide solutions in a pH range of 11.5 to 12.4; (b) mortar; and (c) water-cement grout. Sodium chloride was added to each medium. The techniques investigated were electrode potential, galvanokinetic polarization, constant anodic current polarization, polarization resistance, and resistance probe.

Keywords: *carbon steels, corrosion; reinforcing steels; chlorides, environment; slaked lime, environment; sodium chloride, environment; nondestructive testing; reinforced concrete; corrosion tests.*

93. Vold, R.C., and Hope, B.R. "Ultrasonic testing of deep concrete foundations", Norsk Teknisk Bygge Kontroll, Oslo, Norway; Published by British Journal of Non-Destructive Testing, Vol. 20, No. 5, pp. 232-241, Sept. 1978, England.

Keywords: *nondestructive testing; inspection; ultrasonic testing; ultrasonic equipment; pulse propagation method; sonograms; defects; porosity; voids.*

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94. Vorobjev, V.A., Mosesov, M.D., and Popov, V.P. "Method and automatic system for determination of the surface energy of brittle materials from acoustic emission (crack growth in concrete during freezing and thawing)", Moscow Automobile Highway Institute, Moscow, USSR; Defektoskopiya; Vol. 14, No. 10, pp. 78-82, Oct. 1978, USSR. (Translated in: Soviet Journal of Non-Destructive Testing, Vol. 14, No. 10, pp. 924-027, June 1979.)

Keywords: *mathematical models; energy; acoustic emissions; materials; brittleness; fracture; concrete; nondestructive testing; stresses; cracks; transducers.*

1979

95. ACI Committee 207. "Practices for evaluation of concrete in existing massive structures for service conditions", Concrete International: Design and Construction; Vol. 1, No. 3, Mar. 1979.

Current methods available for evaluating physical properties of concrete in existing structures under service conditions are discussed. The report recommends project design, operation and maintenance records, and in-service inspection data to be reviewed. Existing methods of making condition surveys and nondestructive tests are reviewed; destructive phenomena are identified; methods for evaluation of test and survey data are presented; preparation of final report is discussed.

Keywords: *alkali-aggregate reactions; cavitation; cements; concrete cores; concrete dams; concrete durability; cracking (fracturing); dynamic tests; elastic properties; erosion; extensometers; impact tests; mass concrete; nondestructive tests; pozzolans; seepage; spalling; stresses; X-ray diffraction.*

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96. Ahlsen, U., and Bellander, U. "Estimate of location and diameter of the reinforcement in finished structures" (in Swedish); CBI Research 3:79, Swedish Cement and Concrete Research Institute, Stockholm; 1979, 86 pp.

The aim of this investigation was to produce a nondestructive testing method for routinely documenting the location of the reinforcement, even in heavily reinforced finished structures. A new instrument produced in Poland and used for measuring the location and diameter of quantity of unknown reinforcement, particularly in heavily reinforced in-situ structures, was tested. The accuracy was compared with a conventional cover meter. The effects, if any, of concrete, reinforcement steel grade, measurement equipment, and bundled reinforcement bars were studied.

Keywords: *field tests; measuring instruments; reinforced concrete.*

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97. Amon, J.A., and Snell, L.M. "Use of pulse velocity techniques to monitor and evaluate epoxy grout repair to concrete", Concrete International: Design & Construction; Vol. 1, No. 12, Dec. 1979, pp. 41-44.

Four case histories are presented that show how pulse velocity techniques can be used to monitor and evaluate epoxy grout repairs. The methodology of the evaluations and the limitations of these procedures are discussed.

Keywords: *concretes; epoxy resins; grouting; inspection; nondestructive tests; ultrasonic tests.*

98. Bartos, M.J. "Testing concrete in place", Civil Engineering — ASCE; Vol. 49, No. 10, Oct. 1979, pp. 66-69.

The use of molded cylinders tested in compression to estimate the strength of concrete in a structure is one aspect of modern construction that has remained essentially unchanged during the past 60 years. Recently, however, the testing of concrete in-situ, using the following five methods, has become more widespread: rebound, maturity, pulse velocity, penetration, and resistance to pullout. Test methods and jobs on which they have been used are described.

Keywords: *age-strength relation; compressive strength, concrete construction; cylinders; penetration tests; pullout tests; shotcrete; tests; ultrasonic tests.*

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99. Bazant, Z.P. "Physical model for steel corrosion in concrete sea structures — Theory", Proceedings, ASCE; Vol. 105, ST6, June 1979, pp. 1137-1153; "Application", pp. 1155-1166.

Theory. A physical-mathematical model is developed for concrete exposed to seawater. The model describes: (1) diffusion of oxygen, chloride ions, and pore water through the concrete cover of reinforcement; (2) ferrous hydroxide near the steel surface; (3) depassivation of steel due to critical chloride-ion concentration; (4) cathodic and anodic electric potentials depending on oxygen and ferrous hydroxide; (5) polarization of electrodes due to changes in concentration of oxygen ferrous hydroxide; (6) flow of electric current through the electrolyte in concrete pores; (7) mass sinks or sources of oxygen, ferrous hydroxide, and hydrated red-rust electrodes (based on Faraday law); and (8) rust production rate (based on reaction kinetics).

Application. The theoretical physical model developed in a companion paper is applied to a simplified calculation of corrosion rates and times in relation to corrosion cracking of concrete cover. For determining the extent of cathodic and anodic areas and the thickness of the rust layer, a new principle, stating that the actual corrosion current is maximum, is postulated. Various steady-state corrosion processes are then analyzed. After developing approximate formulas for the time of steel depassivation due to chloride ions and for cover cracking due to volume expansion of rust, a number of numerical examples are given. Diffusivities for chloride ions and oxygen are shown to be usually the controlling factors.

Keywords: *chemical attack; chlorides; concrete durability; corrosion; cracking (fracturing); deterioration; diffusion; electrochemistry; offshore structures; oxygen; reinforcing steels; seawater.*

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100. Bocca, P. "Theoretic-experimental study on the determination of the strength of concrete through extraction tests", Politec. di Torino, Italy, Ind. Ital. Cem.; Vol. 49, No. 1, Jan. 1979, pp. 45-52.

Keywords: *concrete testing; concrete; durability; extraction; nondestructive testing.*

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101. Burger, C.P., and Zachary, L.W. "Dynamic photoelastic study of impulse waves in a concrete gravity dam", Society for Experimental Stress Analysis, 21 Bridge Square, P.O. Box. 277, Saugatuck Sta., Westport, CT 06880, U.S.A.; SESA Spring Meeting, May 1979, San Francisco, CA.

Keywords: *photoelasticity; structural analysis; concrete; nondestructive testing; elastic properties; testing; waves.*

102. Chabowski, A.J., and Bryden-Smith, D. "Simple pull-out test to assess the in-situ strength of concrete", Concrete International: Design & Construction; Vol. 1, No. 12, Dec. 1979, pp. 35-40.

The objective of the research described in this article was to produce a simple test causing little disruption to provide direct information on the strength of high alumina cement concrete in prestressed-concrete X-shaped beams produced under factory-controlled conditions. A pullout test, which is based on the correlation between the compressive strength of concrete and the forces in a wedge anchor needed to produce internal cracking in concrete, was developed. The test method and research leading to its application are described.

Keywords: *alumina cements and concretes; beams (supports); compressive strength; cracking (fracturing); nondestructive tests; prestressed concrete; pullout tests; research.*

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103. Galan, A. "Statistical distribution and statistical characteristics of random quantities used in applications of ultrasound pulse method" (in Slovak), Stavebnicky Casopis (Bratislava); Vol. 27, No. 2, Feb. 1979, pp. 98-118.

The author's results clarify the statistical distribution character of three types of random variables on which the ultrasound pulse method of strength and homogeneity assessment of concrete in the structure is based. At the same time, new knowledge concerning statistical characteristics of these random variables is presented. The newly acquired knowledge allows application of this method to other areas; namely, to an approximately equivalent statistical appreciation of concrete quality in the structure according to standard criteria related to values of cube strength.

Keywords: *concretes; frequency distribution; nondestructive tests; statistical analyses; strength; ultrasonic tests.*

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104. Hawkins, N.M., Kobayashi, A.S., and Fourney, M.E. "Use of holographic and acoustic emission techniques to detect structural damage in concrete members", Experimental Methods in Concrete Structures for Practitioners, ACI Publ. NCC-2; Oct. 1979, Detroit, U.S.A.

The feasibility of using holographic interferometry (HI) and acoustic emission (AE) techniques to determine the extent of debonding between rebars and concrete was investigated. These techniques can be used to detect small surface displacements both in and out of the plane of loading, indicating the load transfer mechanisms throughout the observed area. AE signals generated by internal cracking around the bar are associated with the debonding process for the bar.

Keywords: *acoustic emission; bond; concrete; cracking; debonding; earthquake damage; holographic interferometry.*

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105. Johansen, R. "In-situ strength evaluation of concrete — The 'break-off' method", Concrete International: Design & Construction; Vol. 1, No. 9, Sept. 1979, pp. 45-51.

The paper reviews results and experiences derived from the use of a new in-place testing method, with special reference to its application to an airfield pavement made of vacuum concrete. The testing method determines directly the flexural strength of the concrete in an annular cross-section parallel to the concrete surface and at a definite distance from the surface. The sections to be tested are established by tubular inserts into fresh concrete or by drilling into hardened concrete.

Keywords: *flexural strength; fresh concretes; hardened concretes; inserts; break-off tests; vacuum-treated concrete.*

106. Karpov, V.I., Zatsepin, N.N., and Shaporov, B.D. "Capabilities and optimum parameters of eddy-current probes for the nondestructive testing of corroded steel structural members" (in Russian); Defektoskopiya; Dec. 1979, pp. 52-57.

The degree of corrosion in steel structural members, including reinforcements embedded in concrete, can be assessed by eddy-current probing. A block diagram is given of equipment developed in the NDT Physics Department of the Belorussian Academy of Sciences, for measuring small increments in the resonance voltage and frequency of an inductance probe.

Keywords: *eddy-current testing; corrosion tests; structural members; reinforcing steels, corrosion; manganese steels; carbon steels; nondestructive testing.*

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107. Khilji, Z.M., and Mian, Z. "In-service application of nondestructive testing of concrete structures", University of Engineering & Technology, Lahore, Pakistan; 9th World Conference on NDT, Melbourne, Australia, Nov. 19-20, 1979, Proceedings, Pap. 5A-001.

Keywords: *Concrete; nondestructive testing; ultrasonic applications; concrete construction.*

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108. Kobayashi, A.S. et al. "Detection of rebar debonding by acoustic emission technique", Society for Experimental Stress Analysis, 21 Bridge Square, P.O. Box 277, Saugatuck Sta., Westport, CT 06880, SESA Spring Meeting; May 1979, San Francisco, Calif., U.S.A.

Acoustic emissions (AE) detected by two transducers mounted on a reinforcing bar in a reinforced concrete block that is subjected to cyclic tension-compression loading are used to assess the locations of rebar debonding. Preliminary uniaxial-tension tests of the rebar were conducted to establish the proper level of AE sensitivity, which was then verified by uniaxial-tension tests of rebars embedded in a concrete block. Reasonably good correlations were established between the debonding regions indicated by the AE signals and those detected by dye injected into the cracked concrete.

Keywords: *testing; measurements; adhesion; bars; steel; concrete; acoustic emissions; acoustic variables measurement; acoustic waves; nondestructive testing.*

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109. Mailhot, G., Bisaillon, A., Carette, G.G., and Malhotra, V.M. "In-place concrete strength: New pullout methods", ACI Journal; Proceedings; Vol. 76, No. 12, Dec. 1979, pp. 1267-1282.

Investigations were undertaken to develop pullout tests that could be carried out on finished structures. Three possible approaches considered were: (a) pulling out of tapered anchors placed in drilled holes; (b) pulling out of bolts set in hardened concrete using epoxy; and (c) measuring the force required to cause shear failure of concrete using a split-sleeve assembly. More than 1000 pullout tests using the three techniques were performed. Technique (a) gave relatively poor results in terms of reproducibility and was discontinued. Technique (b) appears promising, but further research is needed. Technique (c) offers good possibilities, and the simplicity of the test makes the method attractive.

Keywords: *anchors (fasteners); bolts; bond (concrete to reinforcement); compressive strength; concrete cores; field tests; nondestructive tests; pullout tests.*

110. Malhotra, V.M. "In-situ strength evaluation of concrete", Concrete International: Design & Construction; Vol. I, No. 9, Sept. 1979, pp. 40-42.

This article reports on a symposium on in-situ strength evaluation of concrete, sponsored by ACI and held in November 1978 at Houston, Texas. A total of 14 papers was presented. They dealt with penetration resistance, pullout, break off, pulse velocity, maturity concept, and combined methods. The presentations and the discussions that followed revealed that, apart from the pulse velocity techniques, the other methods are relatively new, and are only slowly finding acceptance in the concrete and construction industries. Of all the methods discussed at the symposium, the pullout techniques appear to be the most promising for determining the in-situ strength of concrete.

Keywords: *concrete construction; inspection; nondestructive tests; penetration tests; pullout tests; strength tests; ultrasonic tests.*

111. Moldoveanu, T., and Tudorache, G. "Application of micro-seismic methods at the study of concretes and rocks in hydroelectrical structure foundations", Tech. Sci. Pap. Inst. stud. project Hydroenerg, Bucharest, Romania; Vol. 5, 1979, 13 pp.

Keywords: *hydroelectric power plants; foundations; geophysics; seismic; concrete construction; nondestructive testing; rock; seismology; microseismic measurements.*

112. Naik, T.R. "Ultrasonic testing of concrete", Experimental Methods in Concrete Structures for Practitioners, ACI Publ. NCC-2; Oct. 1979, pp. 33, Detroit, U.S.A.

The pulse velocity results should be very carefully interpreted, because various factors affect the value of the ultrasonic pulse velocity. Therefore, it is strongly recommended that the results be interpreted by experienced concrete technologists. Applications of the pulse velocity method are limitless. In the writer's opinion, the only thing limiting its widespread use is the lack of dissemination of adequate information to practicing engineers.

Keywords: *concrete; nondestructive testing; pulse velocity; reinforced concrete; ultrasonic testing.*

113. Philleo, R.E. "Need for in-situ testing of concrete", Concrete International: Design & Construction; Vol. 1, Sept. 1979, pp. 43-44.

There is a definite need for in-situ testing not only to determine the compliance of structures with designs based on the ACI Building Code but also to sort out responsibilities for various aspects of concrete-handling during construction. This article covers the importance of concrete strength testing to ensure construction safety, provide quality concrete, and provide documentation of properly placed concrete.

Keywords: *concrete construction; cylinders; inspection; ready-mixed concrete; strength tests.*

114. Redner, A.S. "Use of photoelastic and Moirê fringe techniques", Experimental Methods in Concrete Structures for Practitioners, ACI publ. NCC-2; Oct. 1979, Detroit, U.S.A.

This is a review of experimental stress analysis using optical methods, with particular emphasis on their application to concrete structures. The discussion encompasses the basic steps of application and typical uses. The methods described are: (1) photoelastic models, their merits and limitations; (2) photoelastic coatings; (3) Moirê fringe technique and its ramifications.

Keywords: *concrete; models; Moirê fringes; nondestructive testing; photoelasticity; polariscope.*

115. Reynolds, W.N., and Wilkinson, S.J. "Nondestructive physical analysis of concrete", NDT Centre, AERE Harwell, Oxon, England. British Journal of Non-Destructive Testing; Vol. 21, No. 1, Jan. 1979, pp. 35-38.

Keywords: *ultrasonic testing; concretes; elastic properties; porosity; density; mechanical variables measurement; physical properties and effects; nondestructive testing; numerical analysis.*

116. RILEM (Réunion Internationale des Laboratoires d'Essais et de recherches sur les Matériaux et les Construction), Paris, France. "Quality control of concrete structures", RILEM conference held in Stockholm, Sweden, June 17-21, 1979; Proceedings, 2 Volumes (in French and English).

The following nine papers on nondestructive testing were published in Vol. 1, and Part 2 of the Proceedings:

a) Bocca, P., Instituto di Scienza delle Construzioni, Politec. di Torino, Italia, "Nondestructive methods for testing strength variations in concrete structures", Part 1, pp. 128-132.

On the basis of experimental results obtained by pullout, ultrasonic, and hardness tests on a large number of specimens, the actual possibilities afforded by these methods in the investigation of concrete strength were analyzed. Special attention is paid to the efficacy of nondestructive testing methods in assessing strength variations from one point to another, a characteristic that cannot be evaluated by destructive testing.

b) Facaoaru, I., Building Research Institute INCERC, Bucuresti, Rumania, "The correlation between direct and indirect testing methods for in-situ concrete strength determination", Part 1, pp. 147-154.

In this paper, direct methods are understood to be methods giving test results for concrete strength directly. By definition, such methods are destructive. A typical example is core-drilling and -testing. Indirect methods are understood to be methods unable to give the strength of concrete directly; their results are another physical property of concrete, from which concrete strength can be deduced. The final aim of such methods is to give concrete strength determinations nondestructively. The main obstacle which has to be overcome is their inaccuracy.

c) Bellander, U., Swedish Cement and Concrete Research Institute, Stockholm, Sweden, "NDT methods for estimating compressive strength in finished structures — evaluation of accuracy and testing system", Part 2, pp. 37-45.

Results from studies of alternative nondestructive testing methods, i.e., other than drilled-out cores, are presented. Testing systems and relationships, which can be applied to structures, have been established. The test methods, based on drilled-out cores, pull out test, the combined method and Schmidt rebound hammer, in that order, show sufficient accuracy, better than that of standard cubes, and might well be used in a performance quality control system.

d) Logothetis, L., and Tassios, T.P., Nat. Tech. University, Athens, Greece, "In-situ assessment of concrete quality by means of three combined NDT methods", Part 2, pp. 105-111.

A combination of pulse velocity and rebound tests together with the Hellenic NDT method is presented here. Estimated local strengths (ELS) thus determined are compared to strengths given by core-testing. Reliable conclusions can be drawn concerning the local quality of the tested area. The mean values of the above-mentioned ELS values are critically compared to the overall conventional strength.

e) MacDonald, C.N., Dow Corning Corp., Midland, Michigan, U.S.A., Ramakrishnan, V., S.D. School of Mines and Technology, South Dakota, U.S.A., "Quality control of concrete using pulse velocity and maturity concept", Part 2, pp. 113-125.

This paper examines the current practice, recent developments, and future prospects of quality evaluation of in-place concrete by using the maturity concept and pulse velocity technique. Based on an experimental investigation using 34 different batches of concrete, single variable equations were developed relating maturity or pulse velocity to the

following concrete properties: compressive strength, tensile splitting strength, modulus of rupture, and modulus of elasticity. Equations for concrete properties based on a single variable are inadequate because of the considerable influence of other variables on these properties. Therefore, empirical equations, derived from linear multi-regression analysis, provide a better means for determining concrete properties.

f) Malhotra, V.M., CANMET, Energy, Mines and Resources Canada, Ottawa, Canada, "A review of an ACI Symposium on in-situ strength evaluation of concrete", Part 2, pp. 121-126.

This paper reports on a symposium on "In-situ strength evaluation of concrete", sponsored by the American Concrete Institute and held in Nov. 1978, at Houston, Texas, U.S.A. A total of 14 papers were presented at the Symposium. They dealt with penetration resistance, pull-out, break-off, pulse velocity, maturity concept, and combined methods. The presentations and the discussions that followed revealed that, apart from the pulse velocity techniques, the other methods were relatively new, yet slowly finding acceptance in the concrete and construction industries. Of all the methods discussed at the symposium, the pull-out techniques appear to be the most promising for determining the in-situ strength of concrete.

g) Meynink, P., and Samarin, A., Ready-Mixed Concrete Ltd., Sydney, Australia, "Assessment of compressive strength of concrete by cylinders, cores and NDT", Part 2, pp. 127-134.

When the strength of in-situ concrete is in doubt because of low test results of cast "standard" specimens, or deterioration, most of the codes permit assessment of concrete quality by testing compressive or indirect tensile strength of cores drilled from relevant parts of a structure. As an alternative to this procedure, nondestructive in-situ testing of concrete can be conducted. The advantage and accuracy of a nondestructive method of in-situ strength evaluation, using both ultrasonic pulse velocity and Schmidt hammer rebound number together, are discussed. A laboratory investigation comparing cylinder, core and nondestructive strength is described, and examples of application of the method are given.

h) Nozaki, Y., Institut Musashi de Technologie, Tokyo, Japan, "Estimating the strength of structural concrete by ultrasonic pulse velocity method", Part 2, pp. 143-150.

To solve the problems associated with estimating the strength of concrete in a structure, some experiments and some case studies of practical cases were carried out. From the investigations, some results are obtained which explain difficulties encountered in measuring the strength of concrete in a structure and analyzing the observations. It is suggested that the strength evaluation be based on as much information as possible, besides pulse velocity, so that the estimation attains validity.

i) Pohl, E., Technische Hochschule Leipzig, DDR, East Germany, "Combined non-destructive testing methods to assess the strength of in-situ concrete for a silo", Part 2, pp.151-158.

A silo having a diameter of 16 m still under construction should reach a height of about 85 m. To obtain reliable data on the quality of the concrete used for the silo, nondestructive testing methods were required. As the situation appeared to be very critical, it was decided to combine various nondestructive testing methods to obtain as accurate an assessment as possible of the compressive strength of the concrete used. The different results corresponded satisfactorily with the determined compressive strength of drilled core values. An economic assessment shows that increased labour productivity and savings in material are possible by using nondestructive testing methods.

117. Slater, J.E. "Corrosion of reinforcing steel in concrete: Magnitude of the problem", Materials Performance, (National Association of Corrosion Engineers, P.O. Box 986, Katy, Texas 77450); Vol. 18, No. 6, June 1979, pp. 34-37.

The magnitude of effects on concrete caused by steel corrosion from deicing salts, and the economic consequences of these effects are discussed. The effects of deicing salt, mainly on bridges, are emphasized. The attacks by marine environments on concrete are not considered. Mechanism of steel corrosion in concrete, detection methods, deck repair procedures, attack rates, and other details are presented.

Keywords: *bridge decks; chlorides; corrosion; costs; deicers; reinforced concrete; reinforcing steels.*

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118. Thornton, H.T., Jr. "Nondestructive testing of concrete T-walls, Atchafalaya Basin protection levees, New Orleans district", U.S. Army Engineer Waterways Experiment Station, Vicksburg; Miscellaneous Paper No. SL-79-18, 1979, 20 pp.

Measurements by nondestructive testing were made on two concrete inverted T-walls constructed in the east and west protection levees of the Atchafalaya Basin. These T-walls are to accommodate a 91-cm (36-in.) crude-oil pipeline that will cross the basin. Ultrasonic velocity measurements were taken through the upright portion of the walls where visible seams of apparent inadequate compaction and exposed reinforcing steel caused concern for the structural integrity of the walls. Measurements were also taken to determine whether any defects in such critical areas as near the intersections of the vertical wall and the base slab had arisen.

Keywords: *compacting; levees; nondestructive testing; pipelines; pipes (tubes); quality control; reinforced concrete; reinforcing steels; structural design; ultrasonic tests; walls.*

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119. Woelfl, G.A., and Lauer, K. "Electrical resistivity of concrete with emphasis on the use of electrical resistance for measuring moisture content", Cement, Concrete and Aggregates; Vol. 1, No. 2, 1979, pp. 64-67.

The paper describes an investigation of the electrical resistivity of concrete. In particular, electrical resistance of concrete was found to increase with decreasing water-cement ratio and increasing aggregate-cement ratio and entrained air content. The results show that calculating a water-concrete ratio by volume provides a convenient way of comparing the electrical resistivity of concretes of different mix proportions. The study also demonstrates that electrical resistance can be used to measure the moisture content of concrete. Electrical resistance increases as moisture content decreases with the least rate of change within the highest range of moisture contents. Although other techniques for measuring moisture content of concrete are more accurate, the use of electrical resistance has the advantage of being a relatively simple procedure requiring inexpensive equipment.

Keywords: *concretes; electrical resistance; mix proportioning; moisture content; water-cement ratio.*

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120. Yamshchikov, V.S., et al. "Vibroacoustic quality control of layered structures", Moscow Mining Inst., Defektoskopiya; Vol. 14, No. 8, pp. 26-35, Apr. 1979 (Translation in Soviet Journal of NDT), Moscow, USSR.

Keywords: *nondestructive testing; measurement; vibrations; acoustic variables measurement; quality control; damping; concrete; mathematical models; impact testing; test equipment; vibration measurement.*

121. Yang, N.C., and Yang, D. "Nondestructive evaluation of airport pavements", Reports No. FAA-RD-78-154: I, II & III, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C.; 1979. (Available from NTIS.)

Volume I: Program references (174 pp.). The concept of nondestructive evaluation and functional pavement design has been integrated in a computer program which is operational at Transportation Computer Centre (TCC) in Washington, DC. The program logic and operational procedures are outlined as follows:

Nondestructive Test — The NDT can be used as a substitute for the plate load test without interference with airport operation. All test data are processed and compiled in an NDT inventory file.

Evaluation and Design — The strength of existing pavements is evaluated in terms of anticipated functional life as governed by cumulative stress damage and progressive surface deformation.

Validation Program — Correlations have been made between the NDT data and subgrade geology, regional climate, airport operation, existing pavements, and response of airport bridges.

Computer Operation — Two operation manuals have been prepared for the execution on computer hardware system at TCC. The program is written in a high-level language FORTRAN IV and involves extensive use of data storage and filing technology.

Volume II: Operation manual for PAVBEN program at TCC (124 pp.). Cost/benefit analysis of alternative pavement design is the primary goal of the PAVBEN program at TCC. The integrated system is data-independent, based on defined mathematical models and operation logic. The job inputs consist of: NDT field data; types of existing pavements; facility classifications; demand forecast; and local cost values.

The major outputs are: NDT inventory file; present functional life; computed engineering data; pavement thickness and cost data; and cost/benefit analysis. The current operation program and this manual are prepared for the execution on a computer hardware system at TCC. Modification of these documents will be required if another computer system is to be used.

Volume III: Operation manual for MLGPAV program at TCC (48 pp.). Sensitivity analysis of aircraft parameters on functional pavement design is the primary goal of the MLGPAV program at TCC. The input data is divided into job and universal default inputs. The job input consists of the aircraft data only, such as: forecast of aircraft movements; maximum takeoff weight; natural frequency of aircraft at tire pavement interface; tire pressure of main landing gear wheel; wheel configuration of main landing gear; and gear spacing. The default system contains all of the data independent of the aircraft, such as: regional cost values; types of facility; runway, taxiway, and apron; navigation system; operation speed; roughness and maintenance standards; subgrade conditions; and airport traffic distribution.

Keywords: *airports; computer programs; concrete pavements; costs; hysteresis; loads (forces); nondestructive tests; runways; structural design.*

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122. Alexander, A.M. "Development of procedures for nondestructive testing of concrete structures. Report 2 — Feasibility of sonic pulse-echo technique", Miscellaneous Paper No. C-77-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg; 1980, 25 pp.

A sonic pulse-echo system has been developed that measures the length of long, thin members, such as piles, and detects discontinuities within the members. A longitudinal pulse is introduced into the concrete at a surface by mechanical impact, and the echo time is measured using the time base of an oscilloscope. The velocity of the longitudinal wave is determined initially on a known length of similar concrete. Pile lengths up to 21.3-cm (70 ft) have been successfully measured using this method.

Keywords: *concrete piles; concrete slabs; nondestructive testing; ultrasonic tests.*

123. American Concrete Institute. "Performance of concrete in marine environment", Special Publication No. SO-65, ACI, Detroit; 1980, 640 pp.

This special publication was developed from a five-day conference held in New Brunswick, Canada, in August 1980. The conference was sponsored by the Canada Centre for Mineral and Energy Technology (CANMET) of Energy, Mines and Resources Canada in association with the American Concrete Institute, the University of New Brunswick, the U.S. Army Corp of Engineers, the Structural Division of the Canadian Society for Civil Engineering. Thirty-three papers were accepted for publication in this volume including: a review of durability of concrete in marine environment; permeability of concrete in sea water; mechanisms and physico-chemical studies of sea-water attack on cement pastes, mortars, and concrete; durability, in marine environment, of concrete containing granulated blast furnace slag or fly-ash, or both; corrosion mechanisms and field tests for reinforced concrete in offshore and coastal structures; bond deterioration due to corrosion of reinforcing steel; and marine corrosion behaviour of reinforced concrete exposed at Tokyo Bay.

Keywords: *calcium compounds; cathodic protection; chlorides; concrete durability; concretes; corrosion; cracking (fracturing); deterioration; exposure; field tests; freeze-thaw durability; harbour structures; marine atmospheres; offshore structures; permeability; portland cements; reinforced concrete; reinforcing steels; repairs; sea water; subsurface structures; temperature; weathering; wetting and drying tests.*

124. Anderson, A.H., Jr. "Investigation, rehabilitation, and maintenance to prevent deterioration of a concrete building", Concrete International: Design & Construction; Vol. 2, No. 9, Sept. 1980, pp. 35-43.

The building is part of a rocket-propellant manufacturing facility and houses equipment for grinding ammonium perchlorate (NH_4ClO_4). The investigation involved examination of the original concrete design data and testing of cores taken from the floor slab, floor beams, and walls. The tests included X-ray diffraction, microscopic analyses of the aggregates, pulse velocity tests, and standard compression tests. Photographic records of crack growth were also studied.

Keywords: *absorption; alkali-aggregate reactions; ammonium compounds; concrete cores; corrosion; cracking (fracturing); crack propagation; deterioration; epoxy resins; maintenance; repairs; sonic tests.*

125. Anderson, G.H. "Cathodic protection of a reinforced concrete bridge deck", Concrete International: Design & Construction; Vol. 2, No. 6, June 1980, pp. 32-36.

The placement of a cathodic protection system on a restored reinforced-concrete bridge deck is presented as a means of arresting corrosion of the reinforcing steel in a chloride-contaminated environment. During the past two years of observation, the top mat of reinforcing steel has been polarized at 300 to 400 mV below the "static" potentials. Corrosometer probe data indicate that further corrosion of reinforcing steel has not occurred since the system was energized. The power required to maintain cathodic protection has averaged about 50 kW per month. As the humidity increases and deck resistance decreases, more current is required to maintain the "set" potentials.

Keywords: *asphalts; bituminous concretes; bridge decks; cathodic protection; chlorides; corrosion; reinforced concrete; reinforcing steels; spalling.*

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126. Annales, Institut du Bâtiment et des Travaux Publics (Paris). "Evaluation of the quality of buildings and equipment by nondestructive methods" (in French); No. 382, Apr. 1980, pp. 117-215.

The proceedings of the ITBTP-CESDA meeting on May 17, 1979, contain 19 papers dealing with measurements of buildings and equipment quality. The selected papers discuss the influence of extensometric recordings for checking the stability of older structures; principles and applications of the granularity technique (speckle) for the recording of displacements (by means of laser photographs); determination of the real static and dynamic behaviour of a building by use of dynamic solicitations (eccentric dynamic loading); new applications of measurment of the sound speed through building materials; X-ray checking of timber and reinforced concrete frames in a building; and investigation of reinforcing bars placed in concrete.

Keywords: *buildings; evaluation; nondestructive testing; quality control; reinforced concrete; static tests; ultrasonic tests.*

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127. Bournat, J.P., Stankoff, A., and Auboiroux, M. "Inspection of concrete platforms: crack detection by current density measurements", Proceedings, XII, Annual Offshore Technology Conference, Houston, Texas; May 5-8, 1980, Vol. II, pp. 247-254.

Keywords: *submersible craft; sensing devices; electric variables measurement; crack detection; nondestructive testing; inspection; cracks; concrete; offshore structures; underwater technology.*

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128. Bungey, J.H. "Validity of ultrasonic pulse velocity testing of in-place concrete for strength", University of Liverpool, England. Non-Destructive Testing International; Vol. 18, No. 6, Dec. 1980, pp. 296-300, ISSN 0308-9126.

Keywords: *concrete; nondestructive testing.*

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129. Chabowski, A.J., and Bryden-Smith, D.W. "Assessing the strength of in-situ portland cement concrete by internal fracture tests", Magazine of Concrete Research (London); Vol. 32, No. 112, Sept. 1980, pp. 164-172.

The results of a program of about 1500 internal fracture tests performed on ordinary portland cement concrete to assess its compressive strength are reported. The influence of the type and size of aggregate on the results and the effect of precompression of the concrete are examined. The variability of the data is assessed statistically to derive relationships between the results of internal fracture tests; i.e., the indicated maximum torques and cube strength as a basis for estimating the compressive strength of in-situ concrete. Considerations affecting the use of internal fracture tests as a means of assessing the strength of concrete in structures in service are briefly discussed.

Keywords: *aggregates; aggregate size; compressive strength; cracking (fracturing); fracture tests; pullout tests; tests.*

130. Frenkel, L.Ya. "Electromagnetic nondestructive evaluation of rebar corrosion in concrete", (in Russian); Zashch. Met.; No. 16 (3), 1980, pp. 377-381.

A portable corrosion detector for nondestructive inspection of concrete reinforcement through a 5- to 50-mm thick concrete layer is evaluated. The detector operates by measuring the difference between the reference and the measured sinusoidal pulses. It consists of a converter, measuring generator, reference generator, mixer, low-pass filter, frequency meter, display, tunable reactor element and a power supply. The optimum operating frequency range, determined experimentally, is 60-80 kHz.

Keywords: *reinforcing steels; corrosion; concretes; environment; electromagnetic testing; detection; corrosion.*

131. Gjorv, O.E., and Vennesland, O. "Cathodic protection of steel in offshore concrete platforms", Materials Performance, National Association of Corrosion Engineers (P.O. Box 218340, Houston, Texas 77218); Vol. 19, No. 5, May 1980, pp. 49-52.

Concrete cylinders with embedded steel connected to cathodically protected steel were exposed to flowing sea water at 20°C. At potentials more negative than 780 mV versus SCE, the bond strength increased. Bond strength for as-received steel was 88% higher than for polished steel. The applied potential caused a reduced chloride penetration through the concrete.

Keywords: *bonding; cathodic protection; corrosion; corrosion resistance; offshore structures; prestressed concrete; reinforced concrete; reinforcing steels; sea water.*

132. Heuze, B. "Cathodic protection on concrete offshore platforms", Materials Performance, National Association of Corrosion Engineers (P.O. Box 218340, Houston, Texas 77218); Vol. 19, No. 5, May 1980, pp. 24-33.

A general discussion of corrosion behaviour of steel inside and outside concrete in sea water and methods of corrosion control provide a background to an analysis of the protective means and criteria basic to adequate potential coordination without interaction hazards. The importance of the duct material in the safeguard of the prestressing tendons, the cathodic protection limitation in case of coating cracking and disbondment, and precautions to be taken against stray currents during welding are discussed. Included is an approach to the corrosion prevention of a drilling, storage, and production platform made of concrete.

Keywords: *cathodic protection; corrosion; corrosion resistance; offshore structures; prestressed concrete; protective coatings; reinforced concrete; reinforcing steels; structural design.*

133. Hymers, W. "Electrically conductive concrete", Concrete Construction; Vol. 25, No. 5, May 1980, pp. 411-415.

Over the years, varying degrees of success have attended efforts to proportion concrete mixes capable of conducting electricity for various applications: grounding, protecting against lightning, eliminating static electricity, environmental heating, and radio frequency interference screening. Electricity can flow in electrolytes or as electrons. Dry concrete has no electrical conductivity but, when damp, can conduct the electricity in the cement mortar. Certain metals, such as aluminum and its alloys and zinc and its alloys, react unsatisfactorily with the highly alkaline cement slurry and grout and are unsuitable for inclusion in concretes. Ferrous metals are a better choice, although some precautions must be observed. Graphite can be used to increase conductivity while retaining strength of the concrete.

Keywords: *aggregates; concretes; conductivity; corrosion; electrical properties; epoxy resins; mechanical properties; metals; polyester; sedimentary rocks; strength.*

134. Johnston, F.T. "Fire damage repaired in concrete silos", Concrete International: Design & Construction; Vol. 2, No. 9, Sept. 1980, pp. 130-131.

Severe explosions and fire occurred at a Lousiana grain company terminal in Louisiana, U.S.A., causing tremendous damage to the concrete, slipformed silos. A Columbus, Ohio, company prepared final drawings and specifications for the silo repairs and provided construction management during the actual repairs, which included demolition and removal of bad concrete and reinforcement, sandblasting, shotcreting, casting new concrete, and pressure injection of epoxy to repair cracks.

Keywords: *concrete cores; damage; demolition; fires; inspection; repairs; shotcrete; silos; strength tests; ultrasonic tests.*

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135. Kobayashi, A.S., Hawkins, N.M., Chan, Y.-L.A., and Lin, I.-J. "Acoustic-Emission Technique", University of Washington, Seattle, WA, SESA Spring Meeting, May 1979, San Francisco, CA. Publ. Experimental Mechanics; Vol. 20, No. 9, pp. 301-308, Sept. 1980.

Acoustic emissions (AE) detected by two transducers mounted on a reinforcing bar in a reinforced concrete block, which is subjected to cyclic tension-compression loading, are used to assess the locations of rebar debonding. Preliminary uniaxial tension tests of the rebar were conducted to establish the proper level of AE sensitivity, which was then verified by uniaxial tension tests of rebar embedded in a concrete block. Reasonably good correlations were established between the debonding regions indicated by the AE signals and those detected by dye injected into the cracked concrete.

Keywords: *acoustic variables measurement; acoustic transducers; nondestructive testing; reinforcing steels; nondestructive testing; acoustic emission; crack propagation; fatigue strength; rebar debonding.*

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136. Malhotra, V.M., and Carette, G. "Comparison of pullout strength of concrete with compressive strength of cylinders and cores, pulse velocity, and rebound number", ACI Journal, Proceedings; Vol. 77, No. 3, May-June 1980, pp. 161-170.

A pullout test, which is a relatively new technique, measures with a special tension ram the force required to pull out a specially shaped steel rod whose enlarged end has been cast into a concrete block. The analysis of the test data shows that a significant correlation exists between the compressive strength of cylinders cured under standard conditions and the pullout strength of concrete. This is equally true for the compressive strength of cores drilled from concrete blocks. The pullout strength is of the same order of magnitude as that of the direct-shear strength of concrete, indicating that the pullout test result may be a measure of the direct-shear strength of concrete.

Keywords: *bond (concrete to reinforcement); compressive strength; concrete cores; concretes; cylinders; impact hammer tests; nondestructive tests; pullout tests; shear strength; ultrasonic tests.*

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137. Morgan, I.L., Ellinger, H., Klinksiek, R., and Thompson, J.N. "Examination of concrete by computerized tomography", ACI Journal, Proceedings; Vol. 77, No. 1, Jan.-Feb. 1980, pp. 23-27.

A computerized tomography system suitable for the examination of concrete has been developed. The system has been used on various test specimens of concrete. The tomograms (cross-sectional density maps) of piers 150 mm (6 in.) in diameter of various cement-to-aggregate mixes show aggregate and voids 1 mm in diameter, and fractures greater than 1 mm wide. The location and density of the background mortar, and the density of the aggregate are accurately reconstructed. A cesium-137 isotopic source was used to provide a 662-keV photon beam. Plastic scintillator strips are used to detect and count each transmitted photon. The technique provides periodic inspection for deteriorating elements subjected to wear and repeated stressing, such as pipe and valves, and provides wear and failure analysis for pipes, concrete piers, and beams.

Keywords: *computers; cracking (fracturing); inspection; measuring instruments; nondestructive tests; quality control; radioactive isotopes; radiography; reinforced concrete; scintillation counters; voids; tomography.*

138. Manning, D.G., and Holt F.B. "Detecting delamination in concrete bridge decks", Concrete International: Design & Construction; Vol. 2, No. 11, Nov. 1980, pp. 34-41.

The corrosion-induced deterioration of concrete bridge decks is a serious problem in locations where deicing chemicals are used. The detection of subsurface fracture planes, or delaminations, is necessary when determining the need or priority for repair and preparing documents for a repair contract. A single, heavy chain is a practical and efficient means of manually identifying delaminations. Infrared thermography has been found capable of detecting delamination because there is a difference in the surface temperature of nondelaminated and delaminated concrete under certain atmospheric conditions. The paper describes the equipment and the factors affecting the infrared imagery when used at ground level and from the air. The technique has the potential to become a routine operational procedure.

Keywords: *bridge decks; bridges (structures); corrosion; deicers; deterioration; temperature measuring instruments.*

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139. Placido, F. "Thermoluminescence tests for fire-damaged concrete", Magazine of Concrete Research (London); Vol. 32, No. 111, June 1980, pp. 112-116.

A new test of fire damage in concrete is proposed based on the technique of thermoluminescence. The thermoluminescence signal remaining in samples of sand extracted from concrete structures is shown to be an indicator of probable fire damage in concrete exposed to temperatures in the range of 300-500°C. The thermoluminescence test is shown to be easy to apply, to require only small samples, and to be a more objective test than those in current use where reinstatement is being considered. An important feature of the proposed test is that it is sensitive to the thermal exposure experienced by the concrete rather than just to the maximum temperature reached.

Keywords: *concretes; damage; fire damage; high temperature; tests; thermoluminescence.*

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140. Runkiewicz, L. "Non-destructive assessment of concrete strength in elements and building constructions" (in Polish); Prace Instytutu Techniki Budowlanej, Warsaw, Poland; Vol. IX, No. 3, 1980, pp. 33-38.

Relations for statistical evaluation of the strength of concrete have been developed for ultrasonic and sclerometric methods with regard to the number of measurements on an element or construction. On the basis of statistical analysis, relations were given for assessment of the warranted, characteristic, and designed strength of concrete in construction.

Keywords: *concrete construction; nondestructive tests; statistical analysis; strength; ultrasonic tests.*

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141. Pullen, D., and Clayton, R. "The radiography of Swaythling bridge", Atom; Nov. 1981, No. 301, pp. 283-288.

The NDT centre at Harwell used an 8-MeV linear accelerator to examine concrete road bridge components up to 1.6 m thick. An initial evaluation was followed by the radiography of Swaythling Bridge in Hampshire. Safety parameters and the results of tests are presented.

Keywords: *Bridges (structures); nondestructive testing; reinforced concrete; radiography; inspection; radiation shielding.*

142. Robert, J.J. "The development of an electrical-resistance technique for assessing the durability of rebars in reinforced concrete blockwork", Cement and Concrete Association, Slough, England; Technical Report: TR-532; ISBN 0-7210-1182-9; 1980, 22 pp.

Tests have shown that an electrical-resistance technique is suitable for determining the amount of corrosion that might take place on the steel in reinforced masonry. Allowance must be made for the influence of temperature upon the gauge resistance.

Keywords: *reinforced concrete; rebars; electrical resistance; electrical resistance meters; corrosion; nondestructive tests; tensile strength; temperature (effect on gauge resistance).*

143. Tomsett, H.N. "Practical use of ultrasonic pulse velocity measurements in the assessment of concrete quality", Magazine of Concrete Research (London); Vol. 32, No. 110, Mar. 1980, pp. 7-16.

Ultrasonic pulse velocity measurements are a particularly suitable way to measure the quality of a concrete structure. This paper indicates some ways in which the pattern of pulse velocity measurements may be used to assess the quality of concrete construction. The suggested patterns have been derived by applying the fundamental relationships, obtained through research, to site surveys and by assessing the deviations permissible before the variations from the normal indicate a defect of engineering significance.

Keywords: *concrete construction; limit state design; nondestructive tests; quality control; ultrasonic tests.*

144. Vassie, P.R. "Survey of site tests for the assessment of corrosion in reinforced concrete", TRRL Laboratory Report No. 953, Transport and Road Research Laboratory, Berkshire; 1980, 36 pp.

A wide range of practical test methods currently being used in the examination of reinforced concrete structures for corrosion are classified according to whether they are destructive or nondestructive; examine the reinforcement of the concrete; provide direct or indirect data on corrosion; or measure, detect, or predict corrosion of the reinforcement. Each technique is considered individually with the significance and the limitations of the method being emphasized. A comparatively high number of measurements per unit area of concrete surface are essential, since the concrete is never uniform and localized corrosion is common.

Keywords: *corrosion; corrosion tests; field tests; reinforced concrete; reinforcing steels (rebars).*

145. Vorobjev, V.A., Golovanov, V.E., and Golovanova, S.I. "Radiation method of determining the granulometric composition of grain components of composition materials", Soviet Journal of Non-Destructive Testing; Vol. 16, No. 9, Sept. 1980, pp. 633-637.

Physical principles of the radiation method of granulometry, the process of generating information on the structure of a composite material, and a method of decoding it are considered. A diagram of a radiation granulometer is presented.

Keywords: *aggregate; concretes; granulometry; nondestructive testing; radiation.*

146. Zubov, G.A., Kustrikov, E.I., and Yavorskaya, V.A. "Experience in the use of nondestructive quality control methods for concrete" (in Russian); Beton i Zhelezobeton (Moscow); No. 7, July 1980, pp. 5-6.

The experience with experiments using the ultrasonic impulse method to assess strength of concrete, and the radioactive isotope method to determine density of lightweight concrete is described.

Keywords: *lightweight concretes; nondestructive testing; radiography; ultrasonic testing.*

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147. Alexander, A.M. "Development of procedures for nondestructive testing of concrete structures; Report 3, Feasibility of impact techniques for making resonant frequency measurements", Miscellaneous Paper No. C-77-11, Report 3, U.S. Army Engineer Waterways Experiment Station, Vicksburg; 1981, 28 pp.

This report investigates the feasibility of using the resonant technique for determining integrity of a field structure and the impact technique to excite the structure rather than sinusoidal or swept-sine technique. Availability of digital Fourier analyzers and mathematical functions, such as spectra, coherence and transfer relationships, permits the analysis of the behaviour of large structures under dynamic conditions in place and in real time. Because the resonant frequency of a structure is directly related to its dynamic Young's modulus of elasticity and therefore its mechanical integrity, the resonant frequency technique is useful in both field and laboratory.

Keywords: *concrete construction; dynamic tests; impact tests; modulus of elasticity; nondestructive tests; resonant frequency; sonic tests (resonance).*

148. American Concrete Institute, Maharashra India Chapter (the Organizing Secretary, 1008/9 Raheja Centre, Nariman Point, Bombay 400 021, India); Symposium, 2 Volumes, 1981, 511 pp.

The first volume includes 53 papers grouped under several themes: Session 1 — techniques for inspection of structures during construction, preventitive maintenance of structures, preconstruction planning and postconstruction follow-up and monitoring; Session 2 — evaluation of damage and rating of structures, nondestructive testing; Session 3 — techniques of rehabilitation of reinforced concrete, prestressed concrete, and steel structures case studies. The second volume collects ten late papers and includes a panel discussion and general reports.

Keywords: *bridges (structures); buildings; concrete construction; damage; inspection; maintenance; nondestructive tests; prestressed concrete; reinforced concrete; repairs.*

149. Andersen, E. "Acoustic emission in concrete" (in Swedish); Nordisk Betong (Stockholm); Vol. 25, No. 2, 1981, pp. 17-20.

In spite of insufficient knowledge of the mechanisms that generate acoustic emission, the method described in this article is an important tool in the investigation of materials. It should be emphasized that, for now, the method is to be regarded as a supplementary source of information. It is expected that its use in materials research will increase toward a better understanding of the relations between the characteristics of the sources and the recorded electric signals.

Keywords: *acoustics; concretes; load tests (structural); strength tests.*

150. Anderson, D.A., and Seals, R.K. "Pulse velocity as a predictor of 28- and 90-day strength", ACI Journal, Proceedings; Vol. 78, No. 2, Mar.-Apr. 1981, pp. 116-122.

As a result of the need for a rapid test method for predicting long-term in-situ strength from short-term nondestructive test measurements, a study was undertaken to evaluate various dynamic test procedures and to recommend a preferred nondestructive test procedure for predicting long-term strength. Based on test data, pulse velocity as a predictor of compressive strength was selected as the preferred nondestructive method among those evaluated.

Keywords: *accelerated tests; compressive strength; flexural strength; nondestructive tests; quality control; resonant frequency; tensile strength; ultrasonic test.*

151. Babkin, L.I. "Determination by ultrasound of the strength of concrete made of aggregates containing carbonate" (in Russian); Beton i Zhelezobeton (Moscow); No. 11, 1981, pp. 8-9.

This article presents results of tests conducted to determine the strength of concrete made of carbonate-containing crushed aggregates. The relation between concrete strength and the various technological conditions of the concrete mix preparation, as well as the characteristics of the components used, are advanced. Ultrasonic analysis permits determination of concrete strength without destroying concrete structures. Concretes made with aggregates containing carbonate have a higher acoustic and mechanical homogeneity than other concretes.

Keywords: *carbonate aggregates; concretes; strength; ultrasonic tests.*

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152. Bevan, C. "Measurement of in-situ concrete strength in Hong Kong", Maunsell Consultants Asia, Shatin New Town, Hong Kong, China, Hong Kong Eng.; Vol. 9, No. 12, pp. 23-31, 1981.

A major disadvantage of the cube test is that the results become available only after the concrete has been placed and hardened. This can, in turn, lead to the need for subsequent nondestructive testing. In most cases of dispute, contractor and client elect to have cores cut from the suspect concrete in an attempt to satisfy themselves regarding the acceptability and soundness of the concrete in the works.

Keywords: *nondestructive testing; mechanical strength; concrete; materials testing.*

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153. Bickley, J.A. "Pullout testing of concrete", Concrete Construction; Vol. 26, No. 7, 1981, pp. 577-582.

The pullout test measures the force required to pull a specially shaped steel rod or disc out of the hardened concrete into which it had been cast. This article describes the procedures for pullout testing, specifically with a portable system that fits into a briefcase. Though many people see a disadvantage in having to preplace inserts in the forms before concreting, in practice the procedure was found to be satisfactory. Another pullout test is described which is designed to be used in test locations selected after the concrete has hardened. This test requires a diamond drill and an expandable insert.

Keywords: *compressive strength; field tests; form removal; mechanical tests; multistorey buildings; nondestructive tests; physical tests; pullout tests; quality control; test equipment.*

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154. Cavalier, P.G., and Vassie, P.R. "Investigation and repair of reinforcement corrosion in a bridge deck", Proceedings, Institution of Civil Engineers (London); Part 1, Vol. 70, Aug. 1981, pp. 461-480.

Since the mid-1960s, large amounts of deicing salts have been used on main roads. Many bridges built before that time lack adequate protection against the harmful effects of these chloride salts on reinforced concrete deck slabs. The use of a half-cell potential test to detect possible corrosion of the reinforcement is reported, and the factors influencing the susceptibility of bridge decks to attack by chloride salts are discussed. An appendix on techniques for monitoring concrete repairs is included.

Keywords: *bridge decks; bridges (structures); chlorides; concrete pavements; concrete slabs; corrosion; corrosion tests; deicers; reinforced concrete; reinforcing steels; repairs; salts.*

155. Concrete Industry Bulletin (Anon.). "Runway testing program", New York; Vol. 21, No. 4, Fall 1981, pp. 20.

An innovative, nondestructive method of testing airport runway pavement will save time and maintenance costs. The nondestructive process uses equipment, mounted on a truck, that simulates moving aircraft weight on the runway. An accelerometer measures the movement of the pavement as it responds to various frequencies and force levels of the applied loads. The strength of the pavement can be determined from these readings. The data are fed into a computer which then outputs a pavement service ability prediction and repair design alternatives.

Keywords: *airports; computers; concrete pavements; costs; evaluation; maintenance; nondestructive tests; repairs; runways.*

156. Concrete Information (Anon.). "Control tests for quality concrete", Portland Cement Association, Skokie, Ill., U.S.A.; 1981, 10 pp. (Reprinted from Design and Control of Concrete Mixtures, EB001.12T, Chapter 14.)

This article covers the major control tests that ensure uniformity of materials, desired properties of plastic concrete mixtures, and required strengths of hardened concrete. Complementary ASTM (U.S.A.) and CSA (Canada) standard tests are discussed. Appropriate testing frequency and guidance for performing tests on aggregates, fresh concrete, and hardened concrete are suggested. Nondestructive test methods are also explained.

Keywords: *aggregate gradation; aggregates; air entrainment; cement content; compressive strength; fresh concrete; hardened concrete; impact hammer tests; moisture content; nondestructive tests; statistical analysis.*

157. Engineers Australia (Anon.). "Spray-on inhibitor helps fight concrete corrosion", Vol. 53, No. 18, Sept. 1981, pp. 33.

This paper briefly describes a method to check anodic and cathodic corrosion of steel reinforcing rods and protect the surrounding concrete. Corrosion is detected by sounding hammers and magnetic detectors, the concrete's affected area is chipped away, the exposed section is blasted with fresh water before heating to 105°C, and this section is then sprayed with a bipolar inhibitor. Air pressure in the hairline cracks is lowered by the heating, reducing surface tension of the inhibitor. After treating the affected section, a mortar mix that consists of 10% inhibitor is used to repair the concrete structure. The area is then coated with a silicone-modified acrylic spray.

Keywords: *cathodic protection; corrosion; cracking (fracturing); protective coatings; reinforcing steels; repairs.*

158. Hansen, A.J. "The mini maturity meter", Nordisk Betong (Stockholm); Vol. 25, No. 4, 1981, pp. 13-15.

This article describes a newly developed measuring instrument: the COMA-meter (COMA — COncrete MAturity). In combination with previously developed pullout tests, this instrument can ensure economical and reliable determination of stripping time and time of load application to concrete structures. This meter is based on relations between heat evolution in concrete and evaporation of a special liquid in a closed tube inserted into the concrete.

Keywords: *concrete construction; measuring instruments; nondestructive tests.*

159. Hartt, W.H., Dunn, S.E., Weng, M.S., and Brown, R.P. "Application of acoustic emission to detection of reinforcing steel corrosion in concrete", Proc Corrosion/81, Toronto, Canada; Apr. 6-10, 1981. Publ: Nat. Assoc. of Corrosion Engineers, P.O. Box 218340, Houston, Texas 77218, U.S.A.

The purpose of the study was to determine whether acoustic emission techniques might be applicable to detection of damage that results from rebar corrosion. Three groups of experiments were performed. The first involved polarization scans upon reinforcing steel, the second addressed accelerated corrosion tests upon reinforced concrete specimens, and the third involved potential monitoring of naturally corroding reinforced concrete specimens. In all cases, the specimens were instrumented so that acoustic emission could be recorded during the test. The conclusion drawn is that acoustic emission monitoring may represent a useful technique for the characterization of corrosion damage to reinforced concrete.

Keywords: *reinforcing steels; nondestructive testing; reinforced concrete; corrosion rate; flaw detection; acoustic emission.*

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160. Kopf, R.J., Cooper, C.G., and Williams, F.W. "In-situ strength evaluation of concrete case histories and laboratory investigations", Concrete International: Design & Construction; Vol. 3, No. 3, Mar. 1981, pp. 66-71.

The critical need for reliable information about in-situ strength of concrete, both for safety and economics, is discussed in detail. Included are the rate of strength gain under various curing conditions and available methods of determining variations in concrete strength in structural elements. Field data, illustrations, actual test reports, and photographs are presented as a proposed basis for the determination of optimal methods and for proper judgement leading to statistical analysis of data.

Keywords: *compressive strength; concrete cores; cubes; curing; cylinders; field tests; form removal; impact tests; nondestructive tests; penetration tests; post-tensioning; prestressing; pullout tests; reinforced concrete; statistical analysis; tests; ultrasonic tests; vacuum-treated concrete.*

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161. Kusenberger, F.N., and Barton, J.R. "Detection of flaws in reinforcing steel in prestressed concrete bridge members", Report No. FHWA/RD-81/087, Federal Highway Administration, Washington, D.C.; 1981, 197 pp.

This report summarizes the development of a practical nondestructive method for detecting deterioration in reinforcement of prestressed structural members of concrete bridges. The problem is thoroughly defined and the technical approach described. The basis for selecting and assessing 15 nondestructive methods is reviewed, and results of a limited laboratory investigation of the magnetic method prior to developing inspection equipment are summarized.

Keywords: *bridges (structures); corrosion; cracking (fracturing); deterioration; nondestructive tests; prestressed concrete; restressing steels; reinforced concrete; reinforcing steels.*

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162. Logothetis, L., and Economou, Chr. "Influence of high temperatures on calibration of nondestructive testing of concrete", Nat. Tech. University, Athens, Greece; RILEM Bulletin, Materials and Structures; Vol. 14, No. 79, Jan.-Feb. 1981, pp. 39.

This work investigates the influence of elevated temperatures of short duration (usually during fires in buildings) on the properties of concrete that affect measurements by nondestructive methods (rebound hammer and pulse velocity). Relationships between strength of concrete as well as rebound and pulse velocity versus heating temperature are established. Finally, the above results are evaluated to find the direct relation between nondestructive measurements and strength of concrete that had been exposed to fire.

Keywords: *aggregates; calibration curves; cement; elevated temperatures; fire exposure; mathematical models; nondestructive testing; ultrasonic pulse velocity testing; rebound test hammer; thermal effects.*

163. Long, A., and Murray, A. "Pull-off test for in-situ concrete strength", Concrete (London); Vol. 15, No. 12, Dec. 1981, pp. 23.

This report briefly relates the background and reliability of the pull-off test to predict the compressive strength of concrete. Until recently, in-situ methods could be categorized simply as either destructive or nondestructive tests. Destructive tests require testing to failure of a complete structural member or concrete core. In pull-off testing a circular steel probe is bonded by an epoxy-resin adhesive to the surface of the concrete under testing. A slowly increasing tensile force is then applied to the probe. Because the tensile strength of the bond is greater than that of the concrete, the tensile strength of the concrete eventually fails.

Keywords: *compressive strength; concrete cores; failure; loads (forces); nondestructive tests; specimens; testing.*

164. Mani, K., and Zacharia, G. "Experimental techniques for assessment of corrosion of steel embedded in concrete in marine environment", Structural Engineering Research Centre, Madras, India; Research Paper, 1981, 12 pp.

The corrosion of embedded steel is revealed only after the surrounding concrete has cracked; the corrosion process would have started much earlier. Visual surveillance has been the widely adopted method of checking the structures for corrosion. As the theory of corrosion process and the influencing factors have been fairly understood, it should now be possible to develop and employ standard procedures and suitable techniques for monitoring structures for detection of corrosion. This paper attempts to describe and discuss possible techniques which can be effectively used for monitoring the structures.

Keywords: *reinforced concrete; reinforcing steels; marine atmospheres; corrosion; sea water corrosion; corrosion mechanisms; nondestructive tests.*

165. Mohr, P. "Inspection of prestressed concrete structures" (in Swedish), Nordisk Betong (Stockholm); Vol. 25, No. 4, 1981, pp. 18-20.

There is a need for information on the condition of the prestressing steel tendons in existing structures. Formerly, large windows had to be cut into the prestressed concrete as preparation for inspection. The use of glass-fibre optics can improve the quality of inspection and, at the same time, make it less destructive and time-consuming.

Keywords: *glass fibres; inspection; nondestructive tests; optical tests; prestressed concrete; prestressing steels.*

166. Malhotra, V.M. "Rebound, penetration resistance, and pulse velocity tests for testing in place", Concrete Construction; Vol. 26, No. 7, pp. 571-575.

Rebound, penetration, and pulse velocity tests estimate the strength of concrete in place. These nondestructive tests are easily performed. Correlations have been established between strength properties and the rebound number shown on a scale on a test hammer. The probable accuracy of predicting concrete strength in a structure with the test hammer is ±25%. The penetration-resistance testing equipment consists of a powder-actuated gun. A probe is fired into the concrete, and the exposed length of the probe is measured by a calibrated depth gauge. The depth of penetration is taken as a measure of compressive strength. A portable pulse velocity test unit electronically measures the time it takes an ultrasonic pulse to pass through concrete. This technique can be used to measure and detect cracks as well as to measure deterioration due to fire. Strength can be predicted with ±20% accuracy. However, these tests do not yield absolute values of compressive strength in a structure, thus they are not substitutes for standard compression tests.

Keywords: *compressive strength; flexural strength; impact hammer tests; mechanical tests; nondestructive tests; penetration tests; physical tests; quality control; test equipment; ultrasonic tests.*

167. Niwa, Y., Ohtsu, M., and Shiomi, H. "Waveform analysis of acoustic emission in concrete", Memoirs, Faculty of Engineering, (Kyoto University, Kyoto, Japan); Vol. 63, Part 4, Oct. 1981, pp. 319-330.

Acoustic emission (AE) is the transient elastic wave emission spontaneously released when materials undergo deformation or fracture, or both, possibly offering a way to monitor structural integrity and characterize mechanical behaviour of materials. Recent developments in AE waveform analysis are described. Results show that original assumptions about AE source mechanisms, mathematically described by the dislocation model, are acceptable. The applicability of elastodynamics and dislocation theory is verified to study the relation between AE source mechanisms and wave motions.

Keywords: *concretes; cracking (fracturing); deformation; mechanical properties; nondestructive tests; waveform.*

168. Runkiewicz, L. "Effect of statistical analysis of nondestructive test results upon assessment of concrete in structures" (in Polish), Building Research Institute Quarterly, Instytut Techniki Budowlanej (ul. Ksawerow 21, 02-656 Warsaw); Vol. 37, No. 1, 1981, pp. 19-27.

This paper examines statistical analysis as a tool in estimating the actual strength of concrete. The principle is advanced that the effect of stress in concrete must be taken into account when evaluating sclerometric tests. Applications to ultrasonic and sclerometric tests are made with examples.

Keywords: *compressive strength; concretes; hardness; nondestructive tests; sclerometric tests; ultrasonic tests.*

169. Samarin, A., and Meynink, P. "Use of combined ultrasonic and rebound hammer method for determining strength of concrete structural members", Concrete International: Design & Construction; Vol. 3, No. 3, Mar. 1981, pp. 25-29.

An empirical equation derived from nonlinear, multi-regression analysis, relating compressive strength, to ultrasonic pulse velocity, and Schmidt rebound number of concrete made with natural dense-weight aggregate is presented. Correlation coefficients of such equation are generally better than 0.9. Hence, using the combined method, compressive strength of in-situ concrete can be evaluated if the type of aggregate used in concrete is known.

Keywords: *aggregates; compressive strength; concretes; elastic properties; impact hammer tests; nondestructive tests; regression analysis; ultrasonic tests.*

170. Steinway, W.J., Echard, J.D., and Luke, C.M. "Locating voids beneath pavement using pulsed electromagnetic waves", NCHRP Report No. 237, Transportation Research Board, Washington, D.C.; 1981, 40 pp.

Pulsed electromagnetic wave technology has been shown useful for locating and sizing voids below reinforced and ordinary portland cement concrete (PCC) pavement. Specific signal-processing techniques have been developed that provide field personnel with information for void detection, with spatial location to within 15 cm (6 in.) and sizing to 1.3 cm (0.5 in.). Signal-processing techniques were implemented on a microcomputer system so that the results could be displayed on a video unit, permanently stored on magnetic diskettes, and printed directly on paper for permanent hard copy. Experimental evaluation of pulsed electromagnetic wave equipment and signal processing techniques for void detection and sizing was done under laboratory conditions. The equipment accuracy, precision, reliability, limitations, and operational characteristics of the equipment were evaluated using 22.9 cm (9-in.) thick sections of reinforced and ordinary PCC pavement, base materials of PCC asphaltic concrete, dense-graded aggregate, and portland cement-stabilized clay. Void depth from 0 to 21.6 cm (8.5 in.) in 1.3-cm (0.5-in.) increments were measured covering several moisture levels.

Keywords: *concrete pavements; reinforced concrete; ultrasonic tests; voids.*

171. Stepisnik, J., Lukac, M., and Kocuvan, I. "Measurement of cement hydration by ultrasonics", American Ceramic Society Bulletin; Vol. 60, No. 4, Apr. 1981, pp. 481-483.

Measurements of the reflection coefficient for ultrasonic waves were used to follow the hydration kinetics of cement pastes under various conditions. The development of the shear modulus of elasticity and the dynamic viscosity were calculated from the data. The data were also used to determine the geometry of the grain growth.

Keywords: *cement pastes; hydration; measuring instruments; modulus of elasticity; ultrasonic tests; viscosity.*

172. Tomsett, H.N. "Nondestructive testing of in-situ concrete structures", Cement and Concrete Assoc., Birmingham, England; Nondestructive Testing Internat.; Vol. 14, No. 6, Dec. 1981, p. 315.

The present status of nondestructive tests (NDT) of concrete and the variety of strength tests, which dominate the technique, are examined. The article proposes that the uniformity and durability of the concrete in a structure are as important as the precise "strength" level of the structure normally measured on the standard specimen. Some of the "new generation" NDT, aimed at testing specific aspects of the potential usefulness of a structure, are briefly described. The article suggests that NDT of concrete will become fully accepted only when the most appropriate test is chosen for a given situation and when economic benefits may be clearly seen to accrue from their use.

Keywords: *concrete; strength tests; nondestructive examination; ND tests.*

173. Tritthart, J., and Geymayer, H. "Non-destructive detection of reinforcement corrosion areas" (in German); Beton Herstellung Verwendung (Dusseldorf); Vol. 31, No. 6, June 1981, pp. 237-240.

When reinforcement corrosion areas are detected early enough, there is still time to carry out necessary repairs. In the U.S.A., potential measurements have been used for 10 years for the nondestructive detection of active corrosion areas in reinforcement, particularly in bridge floor slabs. Necessary bases, test results, as well as conclusions are described in the report.

Keywords: *bridge decks; corrosion; corrosion tests; nondestructive tests; reinforcing steels.*

174. Zivkovic, S. "Testing the concrete quality in structures by combining ultrasound method with concrete cylinder extracting" (in Slavic); Nase Gradevinarstvo (Belgrade); Vol. 35, No. 9, 1981.

This report describes the application of a method to test structural concrete quality based on a combination of the ultrasound method and strength of extracted concrete cylinders. Problems associated with testing small structural elements and concrete of different maturities are discussed. Specific problems connected with the application of the procedure are solved. Conclusions about nondestructive testing procedures are drawn, based on the author's experience in applying these methods.

Keywords: *concrete construction; nondestructive tests; quality control; ultrasonic tests.*

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175. Bickley, J.A. "Variability of pullout tests in-place concrete strength", Concrete International: Design & Construction; Vol. 4, No. 4, Apr. 1982, pp. 44-51.

This article briefly reviews the development of pullout testing. Test data from 18 construction sites, together with relevant correlation results, are analyzed. The pullout test used is shown to have the same order of in-test variation as standard cylinders. Therefore, it measures the in-place strength of concrete and the variation of the results. From this, the minimum strength of concrete in a placement can be calculated, with a high degree of confidence, using standard statistical methods.

Keywords: *compressive strength; pullout tests; standard deviation; statistical analysis; tests.*

176. Bickley, J.A. "Concrete optimization", Concrete International: Design & Construction; Vol. 4, No. 6, June 1982, pp. 38-41.

Acceleration of construction work is achieved by early removal of floor slab forms. Special high-early strength concrete mixes for floor slabs are checked by in-place testing to ensure compliance with specifications. Concrete in the vertical elements, where early strength is not needed, is based on 91-day acceptance requirements. Combining these two approaches results in significant financial savings.

Keywords: *accelerated tests; concrete construction; economics; high-strength concretes; nondestructive tests; pullout tests; tests.*

177. Bocca, P., and Facaoaru, J. "Nondestructive test methods on finite structures: sclerometric tests", 1st Univ. di Archit., Venice, Italy; Ind. Ital. Cem.; Vol. 52, No. 9, Sept. 1982, pp. 703-714, (in Italian with English abstract).

The paper gives indications on the test methods and illustrates the different transformation methods of the measurements of the reflection index in mechanical strength, taking into account the principle of each method, its domain of application and relative precision.

Keywords: *nondestructive examination; concrete testing; mechanics-mathematical models.*

178. Borjàn, J. "Reliability of nondestructive concrete tests", Periodica Polytechnica: Civil Engineering (Budapest); Vol. 26, No. 1-2, 1982, pp. 109-118.

Evaluation of the reliability of nondestructive strength assessment must take into consideration that it is an indirect test used to estimate the resistance of engineering structures to mechanical effects, as are tests to failure. Variables of the nondestructive strength assessment are considered random variables, as are the relationship functions of the variables. A short description of the research is briefly described from which the five statements about the conditions for reliable nondestructive strength assessment were deduced. The procedure has been successfully applied in practice.

Keywords: *compressive strength; concretes; nondestructive tests.*

179. Bracher, D.A., Garrett, D.A., and Heller, C.O. "Theory and design of instrumentation for bridge investigation", Failure Prevention in Ground Transportation Systems, Gaithersburg, MD, Seminar Apr. 22-24, 1980. Publ. U.S. Dept. of Commerce, NBS, Washington, D.C.; Proceedings; 1982, pp. 143-150.

Commercial instrumentation is available for evaluating corrosion of small metal probes that can be embedded in concrete close to the metal of interest. This may be adequate for future concrete bridge footings, but does not address the problem of testing older footings. An "acoustic crack detector" mounted on a back pack is currently used with marginal success. Radiation gauging has been tried and found to give inaccurate diagnostic information. The theory of design for hybrid instrumentation, using both radiation and electromagnetic interrogation for measurement of the integrity of bridge footings, is discussed.

Keywords: *bridges (structures), nondestructive testing; reinforced concrete, nondestructive testing; acoustic emission; probes; electromagnetic testing.*

180. Bungey, J.H. "The testing of concrete in structures", Surrey University Press (Book); 1982, 208 pp.

The principal aim of this book is to provide an overview of in-situ testing of hardened concrete. Within the scope of this book is planning and interpretation of in-situ testing results. The following nondestructive test methods are described: surface hardness method, ultrasonic methods, penetration resistance, pullout, pull-off and break-off methods. Other test methods shown are: magnetic, radioactive, nuclear, electrical, microwave absorption, holographic and acoustic emission techniques, infrared thermography, photoelastic methods, permeability and absorption, pulse echo technique, and integrity testing. Chemical testing and allied techniques, such as chloride determination, micrometric methods, thermoluminescence testing, X-ray fluorescence spectrometry, DTA: differential thermal analysis, thermogravimetry, X-ray diffraction, infrared absorption spectrometry, and scanning microscopy.

Keywords: *aggregates; break-off test; chemical tests; cement; concrete; cores; compressive strength; cube tests; load testing; nondestructive tests; penetration tests; pull-off test; pullout test; surface hardness tests; ultrasonic tests.*

181. Clemena, G.G. "Evaluation of overlaid bridge decks with ground penetrating radar", (Final report), Virginia Highway and Transportation Research Council, Charlottesville, Report No. VHTRC-82-R42; FHWA/VA-82/42; Feb. 1982, 61 pp.

The use of ground-penetrating radar in condition surveys was evaluated on non-overlaid and especially on overlaid bridge decks. The findings presented in this report show that the technique is relatively effective in locating concrete delaminations. It therefore constitutes a rapid, nondestructive means for surveying the condition of bridge decks.

Keywords: *bridge decks; nondestructive tests; pulse radar; radar equipment; radar scanning; defects; concrete slabs; delamination.*

182. Galan, A. "Determination of the compressive strength of concrete by the transverse ultrasonic pulse method and combined methods based on its speed" (in French); RILEM Bulletin, Materials and Structures, Research and Testing (Paris); Vol. 15, No. 85, Mar.-Apr. 1982, pp. 127-133.

A measurement method devised by the author uses the theoretical and measured characteristics of concrete obtained by ultrasonic method; that is, the velocity of propagation of transverse ultrasonic waves v_t, dynamic modulus of elasticity in compressive and tensile loading E_{bu}, and dynamic modulus of transverse elasticity G_{bu}, determined on the basis of their ultrasonic parameters, velocity of propagation of longitudinal waves, and a complex characteristic composed of two pulse velocities (v_t and v_1). This means that to determine the strength of concrete in a building or structural member, it suffices to measure the propagation time of transverse ultrasonic waves and to apply $R = f(v_t)$ expressed by a regression equation.

Keywords: *compressive strength; concretes; ultrasonic tests.*

183. Galan, A. "Transverse ultrasound waves and their use for determination of elastic characteristics of concrete", Slovak Akad. Vied., Stavebnicky Casopis (Bratislava); Vol. 39, No. 6, June 1982, pp. 449-464 (in Slovak with English abstract).

Two ways of measuring the time of propagation of the pulses of the transverse ultrasound wave front are described. They are suitable for direct measurement of the elastic characteristics in cross-sections and parts of reinforced concrete structures and products as well as concrete specimens.

Keywords: *ultrasonic wave-propagation; mathematical models; concrete construction; reinforced concrete; nondestructive testing.*

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184. Girard, R.J., Myers, E.M., Manchester, G.D., Trimm W.L., and Traylor, M.L. "Concrete analysis and deterioration", Transportation Research Board, Washington, DC; Report No. TRB/TRR-853, 1982, 60 pp.

The ten papers in this report deal with the following areas: D-cracking, pavement design, and construction variables; efforts to eliminate D-cracking in Illinois; recycling portland cement concrete pavement; relation between pavement D-cracking and coarse aggregate pore structure; Ohio aggregate and concrete testing to determine D-cracking susceptibility; durability of concrete and the Iowa pore index test; concrete evaluation by radar theoretical analysis; radar as applied to evaluation of bridge decks; effects of concrete deterioration on bridge response; and accuracy of the Chace air indicator.

Keywords: *concrete pavements; structural design; cracking (fracturing); aggregates; portland cements; concrete durability; nondestructive tests.*

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185. Hanaor, A. "Testing of concrete specimens for permeability at cryogenic temperatures", Magazine of Concrete Research (Wexham Springs); Vol. 34, No. 120, Sept. 1982, pp. 155-162.

The permeability of concrete to cryogenic fluids, in the context of use of concrete for storage of liquefied gases, has received very scant attention in comparison with mechanical properties. The tests were carried out by means of a rig specially developed for this purpose. A major feature of the rig is that it fosters an effective method of sealing the specimen under cryogenic conditions. Results obtained indicate that mechanisms governing the permeability of concrete at cryogenic temperatures differ substantially from those prevailing at temperate conditions. Aggregate and aggregate-paste interaction, in particular, play a major role.

Keywords: *cryogenics; liquefied gases; permeability; storage tanks; test equipment; tests.*

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186. Jambor, J., and Zivica, V. "Investigation of corrosion of steel reinforcement in concrete by methods of ascertainment of electrode potential and electrical resistance" (in Slovak); Stavebnicky Casopis (Bratislava); Vol. 30, No. 7, July 1982, pp. 563-586.

Results proved that the values of electrode potential of steel reinforcement in concrete as well as their changes allow highly reliable conclusions to be drawn about corrosion or passive state reinforcement. Further, it is possible to determine the state as well as the corrosion course of reinforcement by use of a new method of electrical resistance measurement. Both test methods complement each other. They are best used simultaneously to determine the state of steel reinforcement.

Keywords: *corrosion; electrical resistance; reinforced concrete; reinforcing steels.*

187. Knab, L.I., and Clifton, J.R. "Cumulative damage of reinforced concrete subjected to repeated impact", Cement and Concrete Research; Vol. 12, No. 3, May 1982, pp. 359-370.

This study was undertaken to develop methods of measuring cumulative damage, which was monitored by measuring the crater depth and the reduction in ultrasonic pulse velocity across the impact region. Crater depth generally increases with increasing number of impacts and therefore was taken to be a reasonable indicator of cumulative damage. The percent reduction in velocity generally increased with increasing number of impacts up to about 40% or more of the total number of impacts to failure. Beyond that, interpretation of the ultrasonic results with respect to the failure mechanism appears necessary.

Keywords: *concrete slabs; damage; impact tests; metal fibres; reinforced concrete.*

188. Matzkanin, G.A., De Los Santos, A., and Whiting, D.A. "Determination of moisture levels in structural concrete using pulsed NMR" (Final Report), Southwest Research Institute, San Antonio, Texas, Federal Highway Administration, Washington, DC; Report No. FHWA/RD-82-008, Apr. 1982, 98 pp.

An investigation has been conducted of nuclear magnetic resonance (NMR) as the basis for nondestructively measuring moisture content in concrete. Results of a laboratory feasibility study conducted on a variety of concrete cylinders showed the NMR signatures to correlate well with evaporable moisture independently of cement type, water-cement ratio, or chloride content; however, magnetic minerals contained in certain aggregates affected the correlation.

Keywords: *concretes; moisture content; nondestructive tests; nuclear magnetic resonance; bridge decks; field tests; reinforced concrete.*

189. Mindess, S. "Acoustic emission and ultrasonic pulse velocity of concrete", International Journal of Cement Composites and Lightweight Concrete (Harlow); Vol. 4, No. 3, Aug. 1982, pp. 173-179.

Both acoustic emission and ultrasonic pulse velocity measurements were used to try to monitor the structural integrity of concrete. Specimens (150-mm cubes) were loaded monotonically to failure, and acoustic emission and ultrasonic pulse velocity were measured simultaneously. Each of four different concrete mixes were tested at ages up to two years to provide a wide range of concrete strengths. The results indicated that ultrasonic pulse velocity measurements began to show internal cracking at stresses of about 33 to 66% of the ultimate stress. This method therefore appeared to be more sensitive to damage than acoustic emissions, which indicated severe cracking but not before it reached about 80 to 90% of the ultimate stress. However, both ultrasonic pulse velocity and acoustic emission seemed to be affected by the age of the concrete.

Keywords: *acoustics; compression tests; compressive strength; cracking (fracturing); crack propagation, failure; mechanical properties; nondestructive tests; ultrasonic tests.*

190. Nesvizhekii, E.G. "Use of the phase method for evaluation defects in the form of developing microcracks", Soviet J. for Nondestructive Testing; Vol. 18, No. 6, June 1982, pp. 453-454.

The use of the phase method made it possible to increase the accuracy and resolving capacity in evaluating the boundaries of microcrack formation in concrete and to investigate the kinetics of failure of the material with insignificant changes in stressed condition.

Keywords: *concrete testing; nondestructive testing.*

191. Placido, F. "Research explores new test method for fire-damaged concrete", Concrete (Chicago); Vol. 46, No. 1, May 1982, pp. 23-27.

This article discusses the application of thermoluminescence (TL) to assess fire damage to concrete and to determine whether reinstatement rather than replacement of the structure is possible. It has been found that temperatures required to remove the stored TL capability of quartz are 300 to 500°C (570 to 930°F), which is the range where the compressive strength of the concrete is affected. Specifics of the test procedure are discussed; two methods for extracting test specimens are evaluated.

Keywords: *compressive strength; concrete construction; fire resistance; high temperature; renovating thermoluminescence.*

192. Proks, M. "Contribution to the use of the ultrasonic impulse method at cement works" (in Czech); Stavivo (Prague); No. 1, 1982, pp. 25-28.

Modern nondestructive methods are one possible way of estimating more quickly the strength of cements being produced. At the Mokra cement works, the ultrasonic impulse method was tested for that purpose. Experience with its application is described.

Keywords: *cements; compressive strength; nondestructive tests; ultrasonic tests.*

193. Reymond, M., Brachet, M., and Raharinaivo. "Test for characterizing damage to concrete using acoustic emission analysis", (in French); Bulletin, Laboratoires des Ponts et Chaussees (Paris); No. 120, July-Aug. 1982, pp. 103-115.

This article discusses a study to characterize, by the acoustic technique, the damage suffered by samples of concrete stressed up to failure point. The study aimed to lead to a better understanding of the physical-chemical and mechanical properties that characterize the concrete cracking process. Three stages of the mechanism of deterioration were determined using the technique before initiation of the crack, and during stable and unstable propagation of the crack in the failure of hardened concrete, through propagation of the crack by extension of a notch cast in a double-cantilever beam. Analysis of the frequency spectra revealed that low-frequency emissions are linked with separation of paste and aggregate at low degrees of stress. When the stresses rise, the emissions contain higher frequencies, characteristic of cracking propagation. Three stages were revealed by acoustic emission in the study of the formation of cracks by preventing strain in the concrete during hardening, prevention of expansion, and shrinkage and prefailure.

Keywords: *acoustics; beams (supports); cracking (fracturing); crack propagation; concrete construction; failure mechanisms; stresses.*

194. RILEM. "International Conference on Concrete of Early Ages", Paris, France; April 6 to 8, 1982.

The following three papers were published in Proceedings, Vol. 1, Session V.

a) Byfors, J., and Cementa, A.B., Sweden, "Pulse velocity measurements for indication of the compressive strength at early ages", pp. 117-128.

b) Casson, R.B.J., and Domone, P.I.J., University College, London, England, "Ultrasonic monitoring of the early age properties of concrete", pp. 129-135.

c) Petersen, C.G., and Hansen, A.J., BKF-Centralen, Danemark, "Timing of loading determined by pull-out and maturity tests", pp. 173-175.

195. Sawamura, I., and Takaha, N. "Investigation on the concrete quality and the deterioration of the Notormisaki Lighthouse" (in Japanese); Concrete Journal (Tokyo); Vol. 20, No. 4, Apr. 1982, pp. 15-22.

This paper discusses the investigation into deterioration of the Notoromisaki Lighthouse built in 1917 in Hokkaido, Japan. Visual inspection, nondestructive concrete testing, concrete characteristics, and the salt penetration into concrete were measured when the structure was demolished. The preparation of drawings for the reconstruction are also discussed.

Keywords: *carbonation; concrete construction; corrosion; deterioration; water-cement ratio.*

196. Sehgal, J.P. "Coping with low-strength concrete", Concrete (Chicago); Vol. 46, No. 3, July 1982, pp. 16-21.

This article lists various factors to check after experiencing low-strength breaks during concrete cylinder testing. A thorough investigation of hardened concrete becomes necessary when serious doubts arise concerning the quality and uniformity of concrete in a structure. Three physical nondestructive tests of hardened concrete are described. It is concluded that control cylinders should not be relied on as the only evidence of concrete quality in structures, because they only indicate potential strength, not necessarily actual strength.

Keywords: *compressive strength; concretes; concrete cylinders; impact hammer tests; nondestructive tests; probes; quality control; sonic tests (resonance).*

197. Shah, Ch.B. "Estimation of strength of in-situ concrete", Indian Concrete Journal (Bombay); Vol. 56, No. 11, Nov. 1982, pp. 292-294.

This article presents an analysis of test results of ultrasonic pulse and rebound hammer methods and shows their correlation with compressive strength.

Keywords: *compression tests; compressive strength; concretes; impact hammer tests; ultrasonic tests.*

198. Shook, J.F., Kallas, B.F., McCullough, B.F., Taute, A., and Rada, G. "Strength and deformation characteristics of pavements", Transportation Research Board, Washington, D.C.; Report No. TRB/TRR-852, 1982, 77 pp.

The eight papers in this report deal with the following areas: Ordway Colorado experimental base project; use of deflection measurements for determining pavement material properties; material layer coefficients of unbound granular materials derived from resilient modulus; moduli of pavement systems from spectral analysis of surface waves; comparative study of selected nondestructive testing devices; back-calculating nonlinear resilient moduli from deflection data; effective moduli and stress-dependence of pavement materials as measured in some heavy-vehicle simulator tests; and Sulphex pavement performance evaluations from laboratory tests.

Keywords: *foundations; pavements; flexural strength; deformation; flexible pavements; bituminous concrete pavements; design; nondestructive tests; performance evaluation; deflection; loads (forces); elasticity; stresses.*

199. Stain, R.T. "Integrity testing — Part 1", Civil Engineering (London); Apr. 1982, pp. 53-59.

This article presents a case for making wider use of integrity testing of concrete piles and briefly describes the methods available. The relative merits and costs of each type are discussed, and a selection chart suggesting the most suitable method for some typical sites is given.

Keywords: *concrete piles; costs; dynamic tests; evaluation; failure; nondestructive tests; soil mechanics; stiffness; ultrasonic tests.*

200. Stain, R.T. "Integrity testing — Part 2", Civil Engineering (London); May 1982, pp. 71-73.

Although failure of main structures due to piling faults is rare, when this type of failure occurs, the results are often catastrophic, such as the collapse of silos and the demolition of multistory buildings. Case histories are presented to demonstrate how substandard piles can be detected. Examples of integrity testing that were able to prove structural soundness and predict working settlement of some pile groups are also discussed.

Keywords: *concrete piles; dynamic tests; evaluation of integrity; failure; nondestructive tests; soil mechanics; stiffness; ultrasonic tests.*

201. Stone, W.C. "Internal strain, deformation and failure of large scale pullout tests in concrete", National Bureau of Standards, Washington, D.C.; Report No. NBSIR 82-2484, 1982, 177 pp.

This report discusses a study performed to obtain detailed experimental data on crack propagation and internal strain distribution using the pullout test method for nondestructive evaluation of concrete. Experimental data indicate that internal cracking and formation of the failure surface are principally governed by the tensile strength of the concrete. Failure surface appears to be formed at 65% of ultimate load; beyond this point, the entire load is carried by the mechanism of aggregate interlock. It is likely that the pullout test measures the shear strength of the cement paste or mortar that binds the concrete together.

Keywords: *aggregate interlock; concretes; cracking (fracturing); crack propagation; failure; failure mechanisms; finite element method; mathematical models; nondestructive tests; pullout tests; strains; tensile strength.*

202. Thaulow, N. "Estimation of the compressive strength of concrete samples by means of fluorescence microscopy", Nordisk Betong (Stockholm); Vol. 26, No. 2-4, 1982, pp. 51-52.

An optical method has been developed for estimating the compressive strength of concrete samples by fluorescence microscopy on small, 3- by 5-cm thin sections of drilled cores. The water-cement ratio is judged by comparing the test sections to standard sections; the air content and cement paste content are measured by quantitative microscopy (either manually or by image analyzer). Strength is then calculated by means of the Feret equation $f_c = 280 \times T^2$. Estimated strength compares favorably with measured compressive strength on drilled cores from a wide range of concrete structures. The method is useful for discriminating cases of low strength due to high water-cement ratio, excess entrained air, poor compaction, cracks, or abnormal hydration.

Keywords: *compressive strength; concretes; microscopic examination.*

203. Tuutti, K. "Corrosion of reinforcement steels in concrete — A method for calculating the length of life of concrete constructions" (in Finnish); Betonituote (Helsinki); Vol. 52, No. 2, 1982, pp. 47-51.

Based on studies in Sweden, two corrosion-initiating mechanisms found in concrete construction are described: carbonation of concrete and excessive chloride concentration in the concrete. In the case of carbonation it has been found that, in the resistance to steel corrosion, a 25-mm concrete cover with a water-cement ratio of 0.75 corresponds to a 17-mm concrete cover with water cement of 0.65 and to a 10-mm concrete cover with water-cement of 0.55. For chloride-initiated corrosion, no general rules may be presented because of the complex nature of the phenomenon. If the structure is not protected from chlorides, its water-cement ratio must not be higher than 0.40. Cracks do not constitute a serious problem, unless both carbonation and excessive chloride concentration are present at the same time.

Keywords: *corrosion; reinforced concrete; reinforcing steels; water-cement ratio.*

204. Waagaard, K. "Fatigue strength evaluation of offshore concrete structures", Proceedings P-56/82, International Association for Bridge and Structural Engineering, Zurich; Nov. 1982, pp. 97-115.

This paper presents a short summary of recommendations for fatigue strength evaluations of offshore concrete structures. Offshore concrete structures are exposed to an environment different from that of land-based structures. These special features are discussed in relation to the design recommendations. As environmental loads are random in nature, the paper discusses how a design recommendation can incorporate random loading. The recommendations are critically assessed in relation to other design rules and recommendations and to the state of the art.

Keywords: *dynamic loads; impact strength; loads (forces); offshore structures; reinforced concrete; structural design.*

205. Yener, M., and Chen, W.F. "Nondestructive in-place testing for fail-safe construction of concrete structures (Part I — A review)", Purdue University, School of Civil Engineering; Structural Engineering Technical Report CE-Str. No. 82-40, 1982, 64 pp.

The final quality of concrete is greatly affected by the quality and proportioning of the constituents which make up the mixed material. The strength of concrete depends on the thoroughness with which the various elements are intermixed, and on the humidity and temperature under which the mix is allowed to cure (harden). To protect against the unintentional production of substandard concrete, a high degree of skillful control and supervision is necessary.

Keywords: *concrete construction; nondestructive testing; concrete mixes and mixing control; quality assurance.*

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206. Akers, S.A.S., and Garrett, G.G. "Acoustic emission monitoring of flexural failure in asbestos cement composites", International Journal on Cement Composites and Lightweight Concrete; Vol. 5, No. 2, May 1983, pp. 97-103.

A comparative study was carried out on the acoustic emission behaviour of asbestos cement composites loaded in flexure. It was confirmed that subcritical cracking can be detected in this material at relatively low loads.

Keywords: *composite material testing; nondestructive testing; acoustic variables measurement; concrete-cracking; asbestos cement composites.*

207. Bungey, J.H. "Non-destructive testing: Part 1", Concrete, (London, England); Vol. 17, No. 8, Aug. 1983, pp. 45-46.

The faster results, lower cost, and lack of damage that result from nondestructive testing allow for more extensive testing, which leads, in turn, to a more comprehensive investigation. Available test methods may be divided into three categories: (1) those that attempt to provide a direct measure of concrete strength, (2) those that assess a parameter that can be used comparatively and sometimes in conjunction with a specific calibration, and (3) those that directly provide information that may be valuable in its own right, other than for the determination of strength. Appropriate situations for employing nondestructive testing are enumerated. Features of the frequently used nondestructive test methods are given in tabular form.

Keywords: *compressive strength; concretes; costs; nondestructive tests; pullout tests; radiography; structural analysis; tests; ultrasonic tests.*

208. Barenberg, E.J. "Longitudinal joint systems in slip-formed rigid pavements", Vol. V, Final Report, Summary of field test results from Chicago O'Hare International Airport; Illinois University at Urbana-Champaign, Department of Civil Engineering, Sponsor: Federal Aviation Administration, Washington, D.C.; Report No. DOT/FAA/RD-79/4-5, Feb. 1983, 55 pp.

Nondestructive tests (NDT) were performed with several types of vibrator and impulse-loading devices, and loading with commercial aircraft. Pavement responses under the various loading conditions were measured using the geophones normally used with the NDT-type equipment, and with deflection gauges and strain meters installed in the pavement slabs. Results from these tests clearly show the importance of load transfer on certain types of distress in concrete pavements, as loss of load transfer efficiency can lead directly to corner breaks and pavement faulting.

Keywords: *pavements; reinforced concrete; joints; runways; airports; nondestructive testing; loads (forces); transverse; longitude; transfer; measuring instruments; geophones; stiffness; failure (mechanics); strain (mechanics).*

209. Chung, H.W., and Law, K.S. "Diagnosing in-situ concrete by ultrasonic pulse technique", Concrete International: Design & Construction; Vol. 5, No. 10, Oct. 1983, pp. 42-49.

This article describes field applications of the ultrasonic pulse velocity technique in testing concrete, using the portable V-meter. Effects of mix proportions, reinforcing bars, and voids are examined. Methods of assessing the uniformity of concrete and detecting voids or honeycombs are discussed. A semi-empirical approach is proposed for estimating concrete strength from pulse velocity measurement. A process is also suggested to approximately assess the fire damage of concrete.

Keywords: *compressive strength; damage; field tests; fires; nondestructive tests; reinforced concrete; statistical analysis; ultrasonic tests; voids.*

210. Clifton, J.R., and Knab, L.I. "Impact testing of concrete", Cement and Concrete Research; Vol. 13, No. 4, July 1983, pp. 541-548.

Three test methods were developed to determine the resistance of concrete subjected to low-velocity, single and repeated impact to failure and to higher-velocity, small projectiles. These performance tests were used to evaluate the effects of reinforcing concrete with one or more of the following reinforcement types: steel fibres, reinforcing bars, or expanded metal. Concretes with and without latex were included. With all three test methods, the results indicate that, in general, increases in the impact resistance were obtained with increases in the compressive strength.

Keywords: *compressive strength; impact tests; reinforced concrete; reinforcing steels.*

211. Dunn, S.E., Hartt, W.H., Young, J.E., and Marshall, R.M. "Application of acoustical emissions to detect and characterize structural damage due to corrosion of reinforcing steel", Quality Test-2, Dallas, Texas; Oct. 25-27, 1983, pp. 14. Publ: American Society for Non-destructive Testing Inc., Columbus, Ohio 43228, 1983 (book).

The deterioration of steel-reinforced concrete caused by the corrosion of rebars is a major concern. The problem is often only recognized when the process has reached advanced stages. Acoustic emission technology is used to detect, locate, and characterize corrosion-induced deterioration of steel-reinforced concrete.

Keywords: *reinforced concrete; nondestructive testing; acoustic emission; reinforcing steels; corrosion.*

212. Gast, R., and Hoba, J. "Non-destructive testing of concrete — Experience obtained with DIN 1048 parts 2 and 4" (in German); Beton (Dusseldorf); Vol. 1, No. 33, Jan. 1983, pp. 20-23.

To determine the strength of existing concrete structural elements, architects and structural engineers often have to test the structures. By applying destructive and nondestructive test procedures of DIN 1048, Parts 2 and 4, the compressive strength of concrete in structures and parts of structures can be determined. A commission for the verification of the values derived from these standards has been formed by the Union of German Concrete Engineers, and experiences with nondestructive testing procedures have been compiled.

Keywords: *nondestructive tests; compression tests; compressive strength; concrete construction; structural members.*

213. Gross, K.P. "New method for determining deformations and crack widths of reinforced concrete load structures" (in German); Materialprufung, Vol. 25, No. 6, June 1983, pp. 193-197.

Laser speckle photography is a new optical method for nondestructive measurement of deformations. The method is also suited for studying test samples made of concrete. The only disadvantages of the method are the sensitivity to movements in the direction of the optical axis and the relatively large amount of work required in the evaluation. A semi-automatic system, which has been in operation for some time, has proven to be very effective in crack detection and crack-width measurement.

Keywords: *concrete testing; nondestructive testing; concrete-crack propagation; laser beams — application, photography.*

214. Knab, L.I., Blessing, G.V., and Clifton, J.R. "Laboratory evaluation of ultrasonics for crack detection in concrete", ACI Journal, Proceedings Vol. 8, No. 1, Jan.-Feb. 1983, pp. 17-27.

A laboratory study was performed to quantify the capabilities of ultrasonic methods to detect cracks in concrete. Pulse velocity and amplitude measurements were taken perpendicular to the crack plane (in cracked concrete) and compared with measurements parallel to the crack plane (in uncracked concrete). A sensitivity ratio was used to determine whether the cracks could be detected. The numerator of the sensitivity ratio was the difference between velocity or amplitude values in the cracked, as compared to uncracked concrete, whereas the denominator represented the variability of the velocity or amplitude values in both the cracked and uncracked concrete.

Keywords: *amplitude; concretes; cracking (fracturing); evaluation; nondestructive tests; ultrasonic tests; velocity.*

215. Ohtsu, M. "Radiation pattern of acoustic emission" (in Japanese); Kumamoto University, Faculty of Engineering, Kumamoto, Japan, Zairyo; Vol. 32, No. 35 G, May 1983, pp. 577-583.

In this paper, fundamental studies with regard to radiation patterns of acoustic emission (AE) wave motions are reported. The types of sources can be classified into two groups from AE characteristics based on the radiation pattern. From the relation between the radiation pattern and the dislocation model, the orientations of dislocation models may be determined. The results show that the determination of source kinematics, with the aid of the radiation pattern, is promising in concrete.

Keywords: *acoustic emission test analysis; material science; concrete tests.*

216. Reimers, P., and Goebbels, J. "New possibilities of nondestructive evaluation by X-ray computed tomography", Materials Evaluation; May 1983, Vol. 41, No. 6, pp. 732-737.

Examples are provided from the results of using a medical scanner producing soft ($\leq$120 keV) X-rays. The resultant picture is affected by spatial resolution, density resolution, electronic noise and artifacts. Computed axial tomography (CAT) provides good detectability of local flaws, such as pores, foreign inclusions, or cracks; examples are provided of various types of flaws including a cracked concrete pier and a cast iron machine part.

Keywords: *cast iron; concrete; nondestructive testing; radiography; computer programs.*

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217. "International conference on in-situ nondestructive testing of concrete", Oct. 2-5, 1984, Ottawa, Ontario, Canada. Proceedings (in English) edited by V.M. Malhotra. Published in Special Publication SP-82, American Concrete Institute (P.O. Box 19150, Redford Stat., Detroit, Mich. 48219, U.S.A.); 831 pp.

The conference was sponsored by Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada, Ottawa, and the American Concrete Institute. Co-sponsors were the Canadian Society for Civil Engineering and the National Bureau of Standards, Washington, D.C., U.S.A. Abstracts of the 38 papers are listed below.

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CANMET/ACI NONDESTRUCTIVE TESTING CONFERENCE PAPERS

218. Malhotra, V.M., CANMET, Ottawa, Canada, "In-situ nondestructive testing of concrete — a global review".

During the past 40 years, in-situ nondestructive testing of concrete has achieved increasing acceptance for the evaluation of existing concrete structures with regard to their uniformity, durability, and other properties. This paper reviews critically the available in-situ nondestructive tests for estimating concrete strength and for determining properties other than strength, and discusses their implications. The methods discussed for estimating concrete strength include surface hardness and penetration resistance tests, pullout, ultrasonic pulse velocity, break-off tests, combined methods, and maturity techniques. The tests reviewed for determining properties other than strength include magnetic, electrical, radioactive, pulse echo, radar, microwave absorption, acoustic emission, nuclear, infrared thermography, and permeability methods.
Some of the tests described are relatively easy to perform, whereas others require sophisticated equipment and trained personnel. Some tests are still in the development stage. Regardless of the type of test used, interpretation of test data must be performed by specialists.

Keywords: *concrete; in-situ nondestructive tests; compressive strength; flexural strength; break-off tests; penetration resistance test; pullout tests; surface hardness tests; ultrasonic pulse velocity method; combined methods; maturity techniques; acoustic emission techniques; electrical, magnetic, nuclear, radioactive methods; microwave absorption technique; permeability tests; infrared technique; pulse echo, radar, thermographic methods.*

219. Akashi, T., and Amasaki, S., Ritsumeikan University, Kyoto, Japan, "Study of the stress waves in the plunger of a rebound hammer at the time of impact".

During the testing of concrete, the nature of the stress waves found in the Schmidt test hammer after impact was examined experimentally. Using a specially designed plunger, the authors observed that the impact of the hammer mass produces a large compressive wave σ_i and a large reflected stress wave σ_r at the centre of the plunger. The ratio σ_r:σ_i of the amplitudes of these waves and time T between their appearance was found to depend upon the surface hardness of cured concrete. The rebound number was found to be approximately proportional to the ratio of the two stresses, and was not significantly affected by the moisture conditions of the concrete. The magnitude of the first stress wave at the centre of the plunger is almost constant and 80% of the value calculated by Schmidt's numerical solution, which does not consider the efficiency of the impact of the hammer.
The authors concluded that, to measure the rebound number of hardened concrete correctly, the Schmidt hammer must be calibrated by first testing a material of constant hardness and then measuring the resulting impact stress wave. By observing the behaviour of the impact stress in the plunger, the surface hardness of concrete can be measured with high accuracy.

Keywords: *compressive strength; concretes; impact stress wave; rebound hammer; rebound number; reflected stress wave; surface hardness; Schmidt test hammer.*

220. Bickley, J.A., Trow Ltd., Rexdale, Ontario, Canada, "Evaluation and acceptance of concrete quality by in-place testing".

The standard method of determining the quality of hardened concrete is the cylinder test. It is usually the only quantitative measure of the quality of concrete in the structure unless test results fail to meet specified values, and other test procedures are called upon for verification. On two large projects in Toronto, horizontal elements were extensively tested by in-place tests to determine the timing for form removal and termination of shoring, and to confirm the specified 28-day strength. Concurrently, cylinders were also made and tested. It was, therefore, possible to evaluate the quality of the concrete on these projects both by standard procedure and by in-place testing.

Keywords: *compressive strength; concrete; concrete quality control; form removal; post-tensioning; pullout; pullout insert; pullout test; standard test cylinders; standard test procedures; statistical analysis.*

221. Bungey, J.H., University of Liverpool, England, "The influence of reinforcement on ultrasonic pulse velocity testing".

Embedded reinforcement may have a significant effect on ultrasonic pulse velocity measurements taken through the structural concrete members. Reliable corrections are essential, if test locations cannot avoid the influence of steel. Extensive laboratory experimental work demonstrates major shortcomings in all currently accepted allowance procedures and confirms that bar diameter is an essential variable to be incorporated. The effect of bars passing across the pulse path is shown to be less than that for bars of similar size running along the path. A correction procedure is proposed that can meet many practical combinations of bar size, bar orientation, and concrete properties with significantly greater accuracy than that possible by established methods.

Keywords: *concretes; in-situ testing; reinforcement effect; ultrasonic pulse velocity method.*

222. Cantor, T.R., and Kneeter, C.P., Port Authority New York, N.Y., U.S.A., "Review of penetrating radar as applied to nondestructive evaluation of concrete".

Practical experiences in the use of downward-looking penetrating radar applied to nondestructive evaluation (NDE) of masonry structures, such as bridge decks, roadways and tunnels, are described. Various configurations of radar and data presentation are considered along with theoretical operational concepts. Specific operational examples are cited, including automatic signal analysis and processing. Discussion of void and other defect detection is included. The ability of radar to gather data rapidly while moving in traffic at speeds of about 16 km/h (10 mph) is reviewed, and its implications for pavement management systems are commented on. Case histories are presented.

Keywords: *cluster analysis; concrete evaluation; cores; data handling; delamination detection; dielectric technique; graphic representation; interference (water, steel); maintenance management (radar for); nondestructive evaluation (NDE); permeativity of concrete; radar penetrating; signature analysis; void detection.*

223. Carette, G.G., and Malhotra, V.M., CANMET, Ottawa, Ontario, Canada, "In-situ tests: Variability and strength prediction of concrete at early ages".

This paper reports on an investigation undertaken to determine the within-test variability at the ages of 1 to 3 days of various in-situ tests currently being used in the field, and to determine their ability to predict, for formwork removal purposes, early-age strength development of concrete. The methods investigated included penetration resistance, pulse velocity, rebound number, and two types of pullout tests. The tests were performed at 1, 2, and 3 days on plain concrete slabs, 300 by 1220 by 1220 mm in size. The test results indicate that the pulse velocity method had the least variability with a within-test coefficient of variation of 0.5%, whereas the rebound method had the highest variability with an average coefficient of variation in the order of 12%. The values for other in-situ tests ranged from 5 to 10%. It is concluded that all in-situ tests, with the exception of the rebound method, can predict the early-age strength development of concrete within a reasonable degree of accuracy, and thus can be applied to determine safe stripping times for removal of formwork in concrete construction.

Keywords: *compressive strength; concretes; in-situ testing; formwork removal; early-age strength; penetration resistance; pulse velocity; pullout test; rebound number; strength prediction; test accuracy; stripping time.*

224. Carino, N.J., National Bureau of Standards, Washington, D.C., U.S.A., "Laboratory study of flaw detection in concrete by the pulse-echo method".

A study was performed to evaluate the applicability of using the echoes from mechanically produced impact to locate hidden defects within concrete. The expected interactions of spherical waves with concrete-air interfaces are reviewed, and the results of experiments using artificial flaws in a large concrete slab are summarized. The following aspects were studied: type of impact source, distance from impact point to receiver, type of receiving transducer, depth of reflecting interfaces, and diffraction effects by sharp edges. The contact time of the impact is shown to be an important parameter for the success of the technique. The influence of the concrete thickness from impact point to the reflecting interface is an area of needed research.

Keywords: *concretes; contact time; defective concrete; diffraction effect; echo receiver; flaws in concrete; impact source; mechanical impact; pulse echo transducer; reflecting interface.*

225. Carlsson, M., Eeg, I.R., and Jahren, P., A/S Scancem, Slemmestad, Norway, "Experience from use of break-off tester".

This paper advocates the use of in-situ testing of concrete and describes the break-off method briefly. Some data are presented from an experimental investigation of break-off testing applied to slip-formed concrete.
Six case histories of the use of the break-off test under field conditions are discussed, and its future applications in concrete testing are considered. In particular, the role of the test in concrete construction in developing countries and as a means of improving testing efficiency in the pre-cast and pre-stressed concrete industries are considered. Relative costs and time requirements for break-off testing are compared with conventional laboratory testing. The authors consider that in-situ testing, and the break-off method in particular, will be used increasingly as more demands are put upon the performance of concrete in a variety of applications.

Keywords: *break-off method; concrete testing; in-situ testing; slip-formed concrete; tensile strength.*

226. Dahl-Jorgensen, E., and Johansen, R., Norwegian Institute of Technology, Trondheim, Norway, "General and specialized use of the break-off concrete strength testing method".

A reliable in-situ testing method, such as break-off testing, provides a more accurate estimate of the concrete strength of the structure than site-cured and laboratory-cured standard specimens. Considerable discrepancy was observed between strength measured in the structure and that on separate specimens cast from the same mix. The test method also proved to be useful when testing bonding strength of concrete overlays and epoxy-coatings to concrete.

Keywords: *break-off method; concrete strength; epoxy coating bond; in-situ concrete strength; laboratory-cured test specimens; overlay bonding strength.*

227. Di Keo, A., Pascale, G., and Viola, E., University of Bologna, Italy, "Core sampling size in NDT of concrete structures".

In this paper a procedure aimed to assess the characteristic value of actual compressive strength of in-situ concrete is presented. It involves: (1) an evaluation of the homogeneity, which may suggest a subdivision of the structure in parts characterized by different estimated strength levels; and (2) a calibration of estimated strength values on the basis of a sample of cores. The experimental values obtained from cores can be used to modify the characteristic value of estimated strength: (a) by means of an appropriate correcting coefficient; and (b) statistically through the Bayesian approach, according to which the mean value of the actual strength is considered a random variable. Consequently, its characteristic value also becomes a random variable. Within the context of the subjective approach to the decision theory, the optimization of the core sampling size is also discussed. Two examples of application of the procedure are reported.

Keywords: *concrete; strength; nondestructive testing; core testing; statistical analysis.*

228. Facaoaru, I., Building Research Institute INCERC, Bucharest, Romania, "Achievements in nondestructive concrete strength estimation in Romania".

This paper summarizes experiences concerning in-situ concrete strength estimation by nondestructive methods. Nondestructive methods such as ultrasonic pulse method and rebound method are presented. The principles for transforming the measured property into concrete strength, taking into account concrete composition and maturity, are given. Details about original developments of nondestructive methods for concrete strength estimation are also presented. Such developments are: (a) combined SONREB method based on pulse velocity and rebound index measurements; (b) sonic coring method, an immersion method using radial transducers adapted for the inspection of deep foundations; (c) acoustic method based on the measurement of the natural period, for the quality control of precast units.

Keywords: *concrete strength; nondestructive testing; ultrasonic pulse velocity; rebound; sonic methods; SONREB (combined method); coring; acoustic shock method; coefficients of influence; natural period; rebound number.*

229. Hansen, A.J., Ottosen, N.S., and Petersen, C.G., In-Situ Testing, Copenhagen, Denmark, "Gas-permeability of concrete in-situ — Theory and practice".

The paper describes methods, theory, and portable apparatus for estimating gas-permeability of concrete in-situ, and the users' preliminary field experiences.
The main test suggested applies low air pressure to the surface of the concrete, and monitors the pressure increase over time for a given depth as a measure of the air permeability. The authors present a theory of induced transient air-flow in concrete and substantiate the theory by laboratory measurements in three qualities of concrete (water-cement ratios of 1.00, 0.55, and 0.40; compressive strength of 10 MPa (1450 psi), 26 MPa (3770 psi), and 86 MPa (12 500 psi), respectively; all types of concrete having 90% relative humidity). The relative humidity must be monitored and, if necessary, corrected. We also describe field experiences with the test.
Other types of in-situ test applications of gas reveal other properties, including microcracks and porosities in the outer surface layer, resistance to carbonation of the reinforcement cover, and bleeding below aggregates during concreting to a depth of 50 mm.

Keywords: *air permeability of concrete; carbonation of concrete; compressive strength; concrete density; gas-permeability; microcracks; relative humidity.*

230. Honig, A., Brno Technical University, Brno, Czechoslovakia, "Radiometric determination of the density of fresh shielding concrete in-situ".

Radiometric determination of density and moisture of soils and building materials has been carried out successfully. Many types of instruments are available. However, instruments are not available for measurements on fresh concrete so that any inhomogeneities cannot be repaired before hardening. The paper describes an analog and a digital radiation density meter and their application in the assessment of the resistance of concrete walls against radiation. By repairing defective concrete in the course of concrete placement it is possible to attain laboratory quality of concrete placement on site. Durability and thermal stability, the measuring procedure, calibration of the instruments, biological shielding tests and the evaluation of the results are described.

Keywords: *radiation shielding; density of concrete; nondestructive testing; radiometry; portable gauge.*

231. Hulshizer, A.J., Edgar, M.A., Daniels, R.E., Suminsby, J.D., and Myers, G.E., United Engineers and Constructors Inc., Philadelphia, Penn., U.S.A., "Maturity concept proves effective in reducing form removal time and winter curing cost".

Two specific areas of concrete work were identified at the Seabrook Station nuclear power plant where the knowledge of developing concrete strengths could be used to reduce cost and time. The maturity method for predicting in-situ concrete strength was evaluated under field conditions to establish it as a dependable, practical approach for the Seabrook work. Based on the test results, the maturity method was used to determine concrete strengths for one application to enable tunnel arch forms to be safely removed after 12 to 14 h, and in another application to reduce heating for concrete-curing in winter by about 30% and shorten curing time by about 2 days.

Keywords: *cold-weather curing; cold weather construction; concretes; early strength estimates; form removal; hydration; in-situ strength; maturity meter; maturity method; nondestructive testing; temperature history; tunnel concreting; Windsor probes; winter curing; young concrete strength.*

232. Kagaya, M., Tokuda, H., and Kawakami, M., Akita University, and Shoya, M., Akita Technical College, Akita, Japan, "A method of estimating the mechanical properties of structural concrete by washing analysis of top layer samples".

The variation in the mechanical properties in the vertical direction can be assessed by the ratio of the difference between the measured value in top layer and that in the bottom layer over standard value obtained from cylinder concrete. The variation in internal composition can be estimated from that of unit coarse aggregate content. A good relationship existed between the degree of variation of unit coarse aggregate content in vertical direction and the ratio of unit aggregate content in the top layer to the specified value. A good relationship between the variation in the mechanical properties in vertical direction and that of the internal composition represented by a ratio relative to the coarse aggregate content was also recognized. The variation in the degree of mechanical properties in the vertical direction could be assessed with good accuracy by measuring only the unit coarse aggregate content in the top layer. The simple and quick procedure developed in this work can be used to study the effect of segregation due to vibration-compaction on the mechanical properties in concrete structures and also to control the quality of concrete placed.

Keywords: *coarse aggregate content; concrete composition; concrete layers; concrete mechanical properties; differences in density and strength; segregation; strength variation; vibration-compaction; washing analysis of fresh concrete.*

233. Kasai, Y., Matsui, I., and Nagano, M., Nihon University, Chiba-Ken, Japan, "Method of rapid air permeability test for concrete on site".

The carbonation rate of concrete depends on the diffusion rate of carbon dioxide and is related to air permeability. This paper deals with a rapid air permeability test for on-site concrete.
The establishment of test method is examined; e.g., the capacity of manometer and the effects of length of hose, recovery height of mercury head, depth of test hole, and existence of neighboring holes on the recovery speed of mercury head and permeability. This test is applied to full-size specimens, and the relationship between the height of concrete placed and the strength of the core, carbonation depth, and air permeability are mentioned.
The suggested test method for air permeability of concrete on site is attached. The outline of test method is as follows: (1) Bore a hole 5 mm in diameter and 40 mm deep; (2) Plug the hole with a rubber stopper and connect to a manometer with an injection needle and plastic hose; (3) Vacuum the system with hand vacuum pump; and (4) Measure the recovery speed of mercury head. The recovery speed is representative of air permeability.

Keywords: *air permeability of concrete; boreholes in concrete; carbonation rate; concrete core strength; diffusion rate; manometer; rapid air permeability test; recovery speed of mercury head.*

234. Keiller, A.P., Cement and Concrete Association, Slough, England, "An investigation of the effects of test procedure and curing history on the measured strength of concrete".

Concrete is usually specified in terms of the strength of standard specimens (normally cylinders or cubes) which are cast from samples of fresh concrete. If the concrete in a structure is to be investigated using core tests, an understanding of the factors that influence the measured strength of a core together with a knowledge of the relationship between the strength of standard specimens and the strength of concrete in structures are required. The paper presents results of both laboratory research and site investigations in which some of the relevant factors have been investigated.

Keywords: *concretes; compressive strength; cores; cubes; core diameter; core orientation; curing conditions; strength relationships.*

235. Khoo, L.M., Singapore Institute of Standards and Industrial Research, Singapore, "Pullout technique — an additional tool for in-situ concrete strength determination".

This paper presents the results of an investigation into a pullout technique for the determination of in-situ strength of concrete. In essence, a pullout test consists of measuring the force required to pull out a specially shaped insert whose enlarged end has been cast into the concrete. In this investigation, pullout tests were performed on 600-mm cubical concrete blocks. Compression strength tests were conducted on standard 15-cm cubes and also on 10- by 20-mm cores drilled from the 60-cm blocks. Statistical analysis of the test data shows that there is a good correlation between the pullout strength and the corresponding compressive strength of cubes and cores. The test is simple, inexpensive, effective, and has an acceptable degree of reproducibility. It has the potential to be a useful additional tool for in-situ quality control of concrete.

Keywords: *compressive strength; concrete strength; in-situ nondestructive test; pullout test; quality control; statistical analysis.*

236. Mlakar, P.F., Walker, R.E., Sullivan, B.R., and Chiarito, V.P., Waterways Experiment Station, Vicksburg, Miss., U.S.A., "Acoustic emission behaviour of concrete".

The acoustic emissions of various concrete specimens under different loadings are studied. First, six monotonic and six cyclic load compression tests on 15- by 30-cm (6- by 12-in.) cylindrical concrete specimens were monitored for acoustic emission. Fundamental data were collected and analyzed, and the Kaiser effect was observed. The data are presented as counts-versus-events to aid in the identification of source characteristics. Next, one multiaxial load (compression and tension) test was monitored. The slope of the counts-versus-events curve for this primarily tension test differed from slopes of curves for the compression test. This difference suggests that the source characteristics of concrete acoustic emissions can be empirically separated and identified. Finally, the emissions detected in a model of a reinforced-concrete circular conduit are discussed.

Keywords: *acoustic emission; concretes; specimens; biaxial stress; Kaiser effect; reinforced-concrete conduits.*

237. Munday, J.G.L., Dundee College of Technology, and Dhir, R.K., Dundee University, Dundee, Scotland, "Assessment of in-situ concrete quality by core testing".

Cores are cut from structural members to establish the quality of in-situ concrete, particularly in terms of uniaxial compressive strength. Although the strength test itself is simple enough, the procedure used has to be carefully established and well understood, because numerous factors can affect the measured value and, hence, the judgement on the quality of concrete. Some of the important factors have been considered in this paper; namely, the diameter of the core; its slenderness ratio (ℓ/d), direction in relation to placing of concrete and location in the structure; curing; cube/core strength relationship and soaking of cores prior to testing. The results obtained are discussed, and recommendations put forward, which could extend the role of core testing and improve the reliability of the test and the interpretation of the results. The existing ASTM and BSI procedures for core-testing are examined in the light of the results obtained. A procedure for the determination of in-situ concrete cube strength is described, and it is suggested that the estimation, from core strength values, of the potential strength of concrete as measured by standard cube tests could give very misleading information and should be avoided.

Keywords: *cores; in-situ concrete strength; core diameter; slenderness ratio; core location; cube/core strength relationship; curing; in-situ cube strength; potential concrete strength.*

238. Murphy, W.E., Cement and Concrete Association, Slough, England, "The interpretation of test results on concrete in-situ and precast structural elements".

The results of tests on in-situ concrete or on precast elements are only of value, if they contribute to the making of valid and useful conclusions relating either to the quality of the concrete mix supplied, or to the performance of the structure in service. The paper indicates how these objectives might be achieved by expressing the strength of the concrete in the structure in terms of an in-situ cube strength. This may be used as a basis for assessing both the standard cube strength of the concrete in a structural element and a design strength that may be used to estimate the performance of the structural element in service.

Keywords: *concretes; cube strength; in-situ strength; precast element strength; quality of mix; service performance of structure.*

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239. Long, A.E., Queen's University, and Murray, A.McC., Department of the Environment, Belfast, Northern Ireland, "The 'Pull-Off' partially destructive test for concrete".

A wide range of approaches are available for estimating the strength of in-situ concrete, including indirect methods (cube- or cylinder-testing), nondestructive methods, and the more recently introduced partially destructive tests. The pull-off test, a partially destructive test, involves bonding a circular steel probe to the concrete surface using an epoxy-resin adhesive, which is stronger than concrete in tension. By measuring the load required to cause a tensile failure in the concrete, the equivalent compressive strength can be estimated by using an appropriate calibration graph. This paper summarizes the results of tests carried out over the past 9 years and includes a comparison with other partially destructive methods currently available. The results of field tests, carried out during the construction of a multistory parking garage, are reported, as well as two case histories relating to commercial applications. In all instances, the feasibility and accuracy of this in-situ test method have been proven.

Keywords: *bond-to-concrete surface; calibration graph; concrete strength; cube test; cylinder test; epoxy-resin bond; partially destructive test; pull-off test; tensile strength.*

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240. Parsons, T.J., National Institute for Occupational Safety and Health, Morgantown, WV, and Naik, T.R., University of Wisconsin-Milwaukee, Wis., U.S.A., "Early-age concrete strength determination by pullout testing and maturity".

This paper reports results of an investigation of the use of pullout testing and the maturity method to predict the early-age strength of concrete. Concrete specimens, composed of 12 variations (two cement types, two aggregate types, and three water-cement ratios), were cured at different temperatures: 2.8°C (37°F), 12.8°C (55°F), 23.8°C (73°F) and ambient temperature. Cylinder compression and pullout tests were performed on specimens at ages ranging from 12 to 168 h (7 days). Regression equations for cylinder strength and maturity, and pullout force and maturity were developed, where the maturity was modified by changing the datum temperature from −10°C to 0°C to improve the predictive capabilities. A model for prediction of the cylinder strength in terms of maturity was developed and a model for the prediction of the concrete strength by the pullout force, which was developed by combining cylinder strength and pullout regression equations. The reliability of the pullout model was affected by the comparative rates of strength gain of the cylindrical specimens and the slab specimens.

Keywords: *compressive strength; concretes; datum temperature; early-age strength; maturity technique; pullout test; regression equation; strength testing; water-cement ratio.*

241. Newman, K., European Ready Mixed Concrete Association, Shepperton, England, "The ready mixed concrete producer's view of in-situ NDT".

This paper examines the influence of workmanship on the properties of concrete and the difference between the results obtained from standard specimen and in-situ tests. Few reinforced concrete engineers appear to understand the relevance and meaning of the results of in-situ/NDT tests. These methods measure concrete properties in the actual structure (i.e., "real-crete") which engineers should be interested in, whereas they still place undue emphasis on the results from standard tests (i.e., "lab-crete"). The respective responsibilities of the ready-mixed concrete producer and contractor are defined. Recommendations are made for improving the reliability of compressive testing by means of standards for testing machines and their use, for differentiating between "lab-crete" and "real-crete" by providing guidance on the assessment of concrete strength in existing structures, and for specifying the required concrete properties in terms of the "lab-crete" compressive strength.

Keywords: *concrete strength; in-situ tests; nondestructive testing; lab-crete (standard tests); real-crete (in structure); ready-mixed concrete.*

242. Okada, K., Kobayashi, K., and Miyagawa, T., Kyoto University, Kyoto, Japan, "Corrosion monitoring method of reinforcing steel in off-shore concrete structures".

The half-cell potential method can be used to assess the progress of reinforcing steel corrosion. The numerical model analysis proposed in this paper can estimate the macro-cell corrosion rate and its distribution along the length of reinforcing steel. Applicability of this method, however, is limited because of disturbance in the electrical circuit caused by water on the concrete surface. The polarization resistance method can also estimate the corrosion rate of steel in concrete structures exposed to various environmental conditions. But the application of this method on-site requires embedment of a small steel specimen into the structures. In this study, the square-wave current polarization with compensation for concrete resistance is used to measure the polarization resistance of steel in a model specimen. The results indicate that both monitoring methods compensate for the disadvantages of each other and can be utilized as the corrosion monitoring techniques. Their effectiveness depends upon the environmental conditions of the offshore concrete structures.

Keywords: *corrosion monitoring; environmental condition; half-cell potential; polarization resistance; macro-cell; micro-cell; chloride corrosion; maintenance; repair.*

243. Rebic, M.P., Institute for Testing and Research in Materials and Structures, Ljubljana, Yugoslavia, "Distribution of critical and rupture loads and determination of the factor of crackability".

During the compressive loading of 20- and 10-cm concrete cubes, acoustic emission (AE) and the ultrasonic pulse transit time were measured. The critical load (σ_c) at which the internal structure of the concrete begins to be damaged is determined from the AE-σ and transit time/σ diagrams. The ratio between σ_c and the rupture load (σ_r) is defined as the crackability factor $F = \sigma_c/\sigma_r$. This factor increases from zero (for ideally ductile materials) towards a value of 1.0 (for completely brittle materials). From the tests described, it follows that the factor F has practically the same value whether it is determined from AE or ultrasonic measurements. Statistical distribution of the factor F is wider than that of the rupture loads, which means that the start of the irreversible changes lies in a wider range of loading than the rupture load.

Keywords: *acoustic emission; concrete; crackability factor; critical load; pulse transit time; rupture load; ultrasonic pulse velocity.*

244. Robins, P.J., Loughborough University of Technology, Loughborough, England, "The point-load test for tensile strength estimation of plain and fibrous concrete".

Whereas compressive testing is by far the most common method for testing cores, there exists a need for a method of tensile-strength estimation. The point-load test is investigated for its potential to satisfy this need, and the results of over 800 point-load core tests carried out on a plain, fibrous, and sprayed fibrous concretes are discussed. A good straight-line relationship between flexural strength and 68-mm core point-load strength is obtained for both plain and fibrous concretes. The average values of the coefficient of variation of point-load strengths for plain and fibrous concretes were both between 8 and 9%; this compares with a value of 6% for the flexural strengths. The point-load method is shown to be of particular potential for assessing the strength properties of sprayed fibrous concretes.

Keywords: *concrete cores; fibrous concrete; in-situ testing; point-load index; sprayed concrete; tensile strength.*

245. Roper, H., Baweja, D., and Kirkby, G., University of Sydney, Sydney, Australia, "Towards a quantitative measure of durability of concrete structural members".

Brief consideration is given to the uses of a quantitative measure of durability of concrete structural members. A classification scheme of structures, elements, causes and effects is reviewed by the use of examples. Any quantitative measure of durability of in-situ structural members must be based on data gathered using nondestructive test methods. For any phenomenon, such as cracking, corrosion, or spalling, which influences durability, three factors must be considered: (1) a method of measurement of the phenomenon, (2) the intensity of the phenomenon, and (3) its distribution over the observed area.

Keywords: *durability of concrete; classification of structures; quantitative measurements, nondestructive tests; optical analysis.*

246. Samarin, A., BMI Ltd., Sydney, Australia, and Dhir, R.K., Dundee University, Dundee, Scotland, "Determination of in-situ concrete strength; rapidly and confidently by nondestructive testing".

The determination of concrete properties, using theoretical or empirical relationships, or both, is commonly used in the design and construction of concrete structures. It is argued that, at best, all such estimates could only be approximate, given the varied nature of concrete due to its intrinsic makeup and workmanship, besides such factors as environmental conditions and age. The use of nondestructive testing of concrete should be assessed against this background. A method combining the rebound hammer and pulse velocity readings is explained. From the studies undertaken in Australia and Scotland, it appears that the combined methods could help to further increase the confidence in estimating the strength of in-situ concrete.

Keywords: *in-situ concrete strength; nondestructive tests; Schmidt test hammer; ultrasonic pulse velocity; combined-method application.*

247. Sturrup, V.R., Consultant, Etobicoke, Ont.; Vecchio, F.J., and Caratin, H., Ontario Hydro, Toronto, Ont., Canada, "Pulse velocity as a measure of concrete compressive strength".

Relationships can be established for concrete between the pulse velocity and concrete strength, but they are influenced by many factors. Of particular significance are the proportions and composition of concrete components, age, curing conditions and moisture content of the concrete. A relationship established at early ages is not applicable as concrete matures. A relationship determined on sound concrete during its hardening stage cannot be used to predict the strength of the same concrete after it has hardened. Such a relationship should be established on cores from the concrete in question. A relationship established using laboratory-cured specimens cannot be used with assurance to follow strength development in a structure. The relationship between pulse velocity and concrete strength can be confused by cracks, voids, or other discontinuities in the concrete.

Keywords: *admixtures; aggregates; composition (concrete); cracks; density; freezing and thawing; moisture content; pulse velocity; strength; temperature (concrete); voids.*

248. Swamy, R.N., University of Sheffield, England, and Al-Hamed, A.H., National Centre for Construction Laboratories, Baghdad, Iraq, "Evaluation of small diameter core tests to determine in-situ strength of concrete".

This paper presents tests on cores 50 mm in diameter. To evaluate the in-situ strength of concrete, cores with height-to-diameter ratios of 1 and 2 were drilled vertically from slabs, which had been cured in an uncontrolled internal environment to simulate conditions in practice. The variables investigated include different concrete strength levels, mix proportions, age, size and type of coarse aggregate, and concrete type, i.e., normal and lightweight. The core strength results are analyzing the height-to-diameter correction factor and the relation between core strength and cube strength. The core strength results are related to core and cube pulse velocity and Windsor probe test results.

Keywords: *concretes; concrete strength; drilled cores; in-situ concrete strength; pulse velocity; Windsor probe test.*

249. Swamy, R.N., University of Sheffield, England, and Al-Hamed, A.H., National Centre for Construction Laboratories, Baghdad, Iraq, "The use of pulse velocity measurements to evaluate in-situ concrete strength".

Paste efficiency concept based on the pulse velocity difference between a control specimen and the concrete in the structure, can be used to estimate the air-dried cube strength and, hence, in-situ concrete strength. This paper presents extensive test evidence to substantiate the validity of using paste efficiency to estimate the probable strength distribution in a structure prior to construction. The results show that the "k" values relating the strength of control specimen to the strength of concrete in structure depend on concrete mix proportions, cement content, size and type of coarse aggregate, and the type of concrete. Based on this project, a set of "k" values is recommended for estimating in-situ strength to within 10%, and these values should apply to site conditions with reasonably good quality control. The paper shows that pulse velocity measurements based on paste efficiency concept can offer a reliable and consistent method of estimating air-dried cube strength, which is shown to have some correlation to core strength.

Keywords: *air-dried cube strength; concrete strength; drilled core strength; in-situ strength of concrete; "k" factor; paste efficiency concept; pulse velocity.*

250. Takabayashi, T., Yoshino Rika Kogyo Co. Ltd., Tokyo, and Ishida, H., Shibaura Institute of Technology, Shibaura, Japan, "Measurement of thickness of concrete structures".

This paper describes a method of measuring the thickness of concrete pavement and concrete structural members. A particular feature of this method involves the combined use of the ultrasonic pulse and resonance methods to compute the thickness of concrete by measuring the pulse velocity and resonant frequency of concrete.

Keywords: *concretes; pavement thickness; nondestructive testing; resonant frequency; thickness of concrete; ultrasonic pulse velocity method.*

251. Tamura, H., and Yoshida, M., General Building Research Research Corp., Osaka-fu, Japan, "Nondestructive method of detecting steel corrosion in concrete".

This paper presents a new nondestructive method for detecting corrosion of reinforcing steel in concrete. The state of corrosion of steel can be electrochemically estimated by using not only natural potential, but also polarization and electrolyte resistance. These three electrochemical values can be measured with a polarization resistance meter and a two-electrode probe set on the surface of concrete covering steel. These values are only apparent, because they consist of the values in both anodic and cathodic sites. The authors therefore analyzed the relationship between the measured apparent values and real values in an equivalent electric circuit reflecting the corrosion phenomenon in concrete. Furthermore, the relationship between the various kinds of electrochemical characteristics was evaluated by a numerical study. In-situ application of the new nondestructive method is also presented.

Keywords: *nondestructive method; corrosion state; corrosion rate; corrosion current; steel; reinforced concrete; electrochemical characteristics; natural potential; polarization resistance; electrolyte resistance; electric circuit.*

252. Tanigawa, Y., Baba, K., and Mori, H., Mie University, Kamihama cho, Japan, "Estimation of concrete strength by combined nondestructive testing method".

The purpose of the present paper is to obtain a practical expression for estimating the compressive strength of concrete using the nondestructive testing method by combining rebound number with ultrasonic pulse velocity, and to discuss its applicability to the evaluation of the strength of concrete members or structures.
Experimental investigations were carried out to examine the effects of such factors as water-cement ratio, the maximum size and volume fraction of coarse aggregate, the curing condition, and the age of concrete. Accuracies of the prediction, expressed in various types of empirical formulas are examined by multiple regression analysis, and practical equations for estimating concrete strength are proposed. The equations are applied for evaluating the strength distribution in a concrete column and in an existing concrete building.

Keywords: *combined nondestructive testing method; compressive strength; regression analysis; Schmidt test hammer technique; ultrasonic pulse velocity method.*

253. Uomoto, T., and Kobayashi, K., University of Tokyo, Tokyo, Japan, "In-situ test to determine fiber content of steel fiber reinforced concrete by electro-magnetic method".

To control the quality of steel-fiber reinforced concrete (SFRC), determination of fiber content is one of the most important concerns in practice. Although SFRC is often assumed to be satisfactorily mixed by any concrete mixer, uniform fiber content cannot always be obtained, if mix proportions and mixer design are unsuitable. To deal with the problem of nonuniform fiber contents, a simple in-situ test is needed to check the quality of SFRC before it is cast. The fiber content of SFRC can be determined by using techniques such as X-ray image analysis, separation by washout analysis, and an electro-magnetic method. However, some of these techniques are too troublesome to be used as in-situ tests.
The special electro-magnetic method described here is not only applicable to hardened concrete but also to fresh concrete. Fiber content can be measured within a few minutes, whether the test is performed in the laboratory or on the job. The proposed method of measuring fiber content is discussed from the point of view of practical problems, such as the effects of distribution and orientation of fibers. This method has been introduced as a standard test for SFRC in Japan.

Keywords: *in-situ test; fiber content; electro-magnetic method; steel-fibre reinforced concrete; fresh concrete; hardened concrete; electro-magnetic attachment.*

254. Vogt, W.L., and Beizai, V., MRA Materials Engineers Inc., Houston, Tex., and Dilly, R.L., University of Houston, Houston, Tex., U.S.A., "In-situ pullout strength of concrete with inserts embedded by 'finger placing'".

A review of available literature indicates that the "finger-placing" technique of embedding pullout inserts in concrete after placement has not been used for determining and reporting the in-situ concrete strength development during construction. Early strength information may be a useful guideline for form removal, stressing, or reshoring. This technique of embedding pullout inserts to determine the strength of hardened concrete was used during the construction of a box culvert requiring approximately 11 500 m^3 of concrete. Thirty locations on the structure were tested to determine the force required to extract embedded inserts at ages of 2, 4, and 7 days. Generally, higher pullout forces were required to extract inserts as the concrete matured. Currently, no criteria exist for evaluating the pullout test results; however, the data obtained throughout this study appears to be normally distributed at early ages. The standard deviation and within-test variation values are higher than expected. Improvements in these parameters may be achieved by improvements in finger-placing and testing techniques.

Keywords: *concrete strength; early strength; evaluating pullout test results; "finger-placing" technique; form removal guideline; in-situ concrete strength; pullout inserts; reshoring; stressing.*

255. Whiting, D., Construction Technology Laboratories, Skokie, Ill., U.S.A., "In-situ measurement of the permeability of concrete to chloride ions".

An electronic device and test procedure that can be used to rapidly assess the permeability of various types of concrete to chloride ions is described. The method consists of monitoring the amount of electrical current passed through a test area on a concrete slab when a potential difference of 80 Vdc is maintained across the specimen for a period of 6 h. Chloride ions are forced to migrate out of a sodium chloride solution subjected to a negative charge through the concrete towards reinforcing steel maintained at a positive potential. Development of a prototype device and testing on small-scale laboratory slabs of ordinary portland cement concrete, latex modified concrete, internally sealed concrete, dense ("Iowa") concrete, polymer-impregnated concrete, and polymer-concrete are described. In addition, field trials carried out on a conventional concrete deck and a deck overlaid with dense ("Iowa") concrete are discussed. The method gives a good correlation with long-term bonding data on companion concrete slabs. It can be used as a quality control tool for new construction or as a means of monitoring permeability of structures currently in service.

Keywords: *bridge decks; chlorides; latex; nondestructive tests; on-site tests; overlays; permeability; polymer concrete.*

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